Centre for Medical Image Computing

Dementia Research Centre

Medical Image Registration
Concept and application examples

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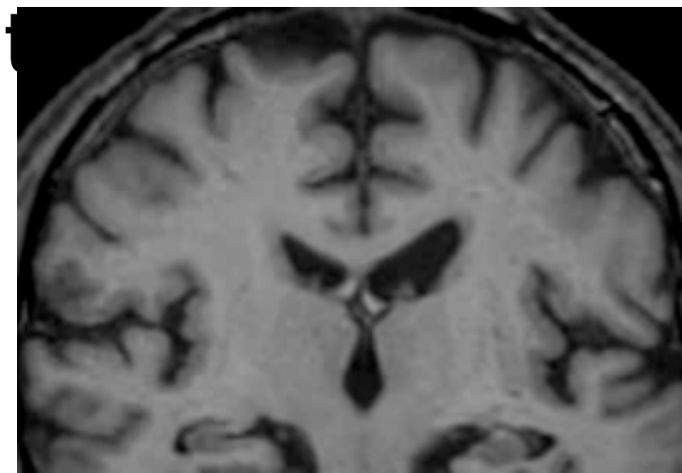


Outline

- What is medical image registration?

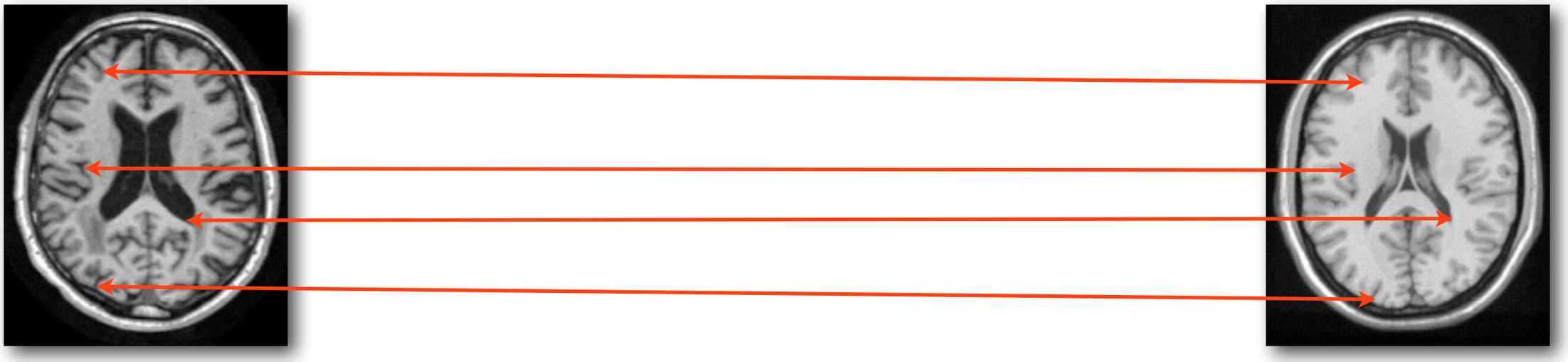
- How does it work?

- Application examples

➡ *Note: This has to be clear.*
Please do ask question!!!

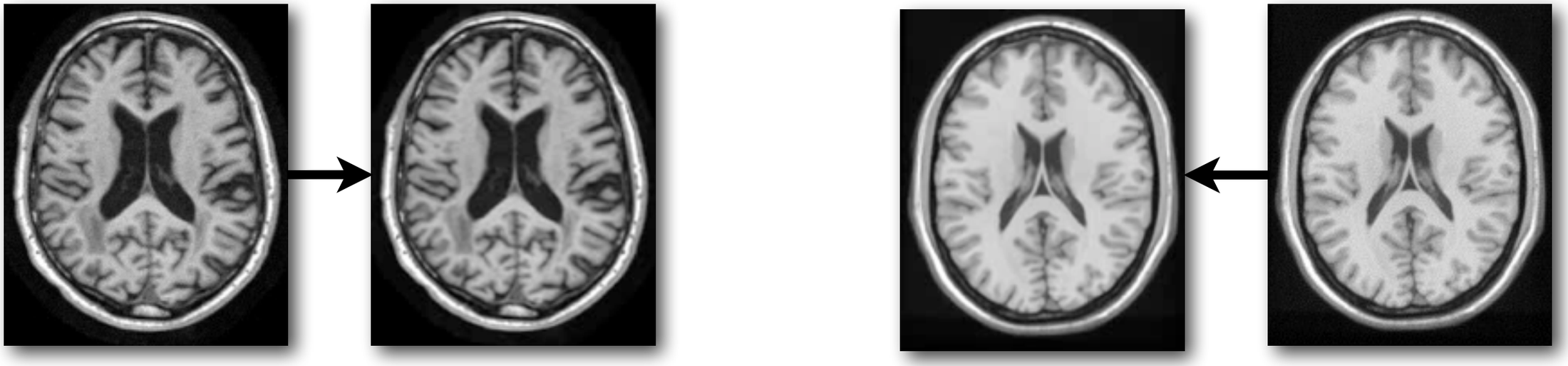
What is medical image registration?

- Aim: Establishing spatial correspondences



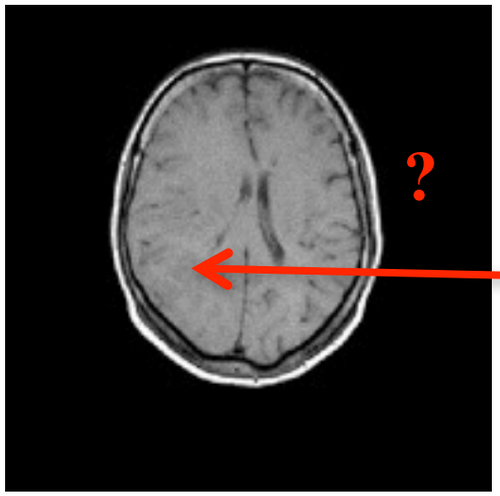
What is medical image registration?

- Aim: Establishing spatial correspondences

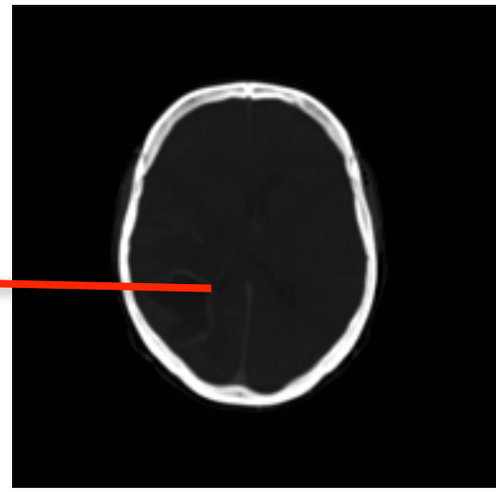


What is medical image registration?

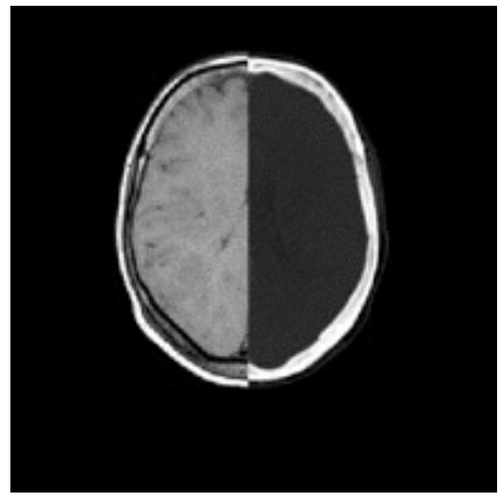
- What is a mapping?
  A coordinate transformation between two images.



The MRI is the static, ***reference*** *(or target image)*



The CT is the moving, ***floating*** *(or source image)*



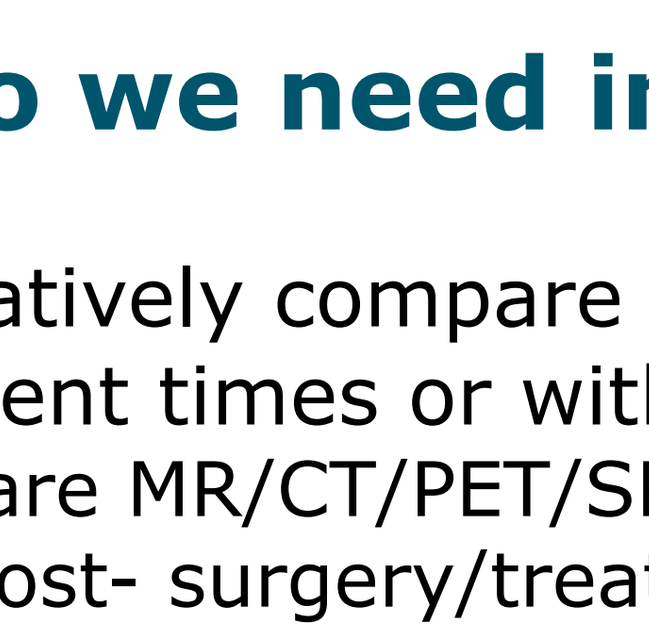
Challenge: *intensities are representing different tissue types...*

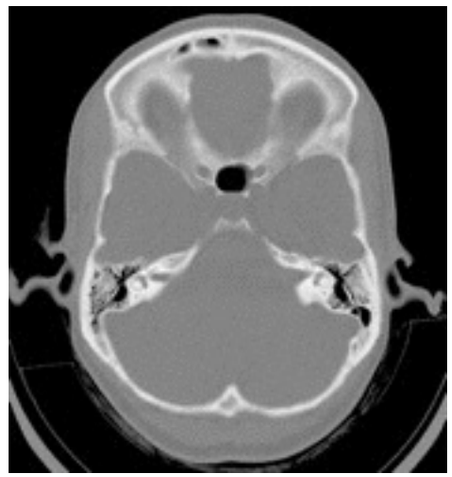
- Registration is about obtaining the best mapping, a transformation **T**()
  - **T**() maps points in the two images: $\mathbf{X}_{MRI} = \mathbf{T}(\mathbf{X}_{CT})$

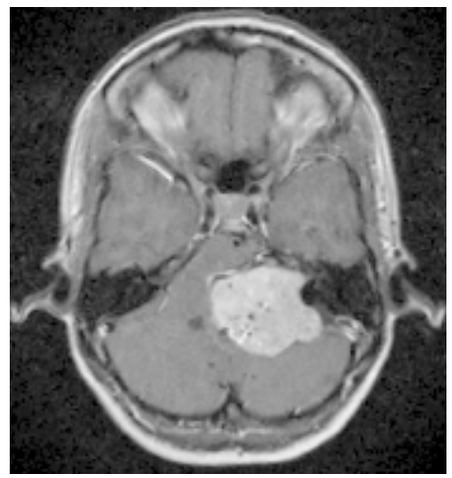
- Registered images can be 2D, 3D or 4D

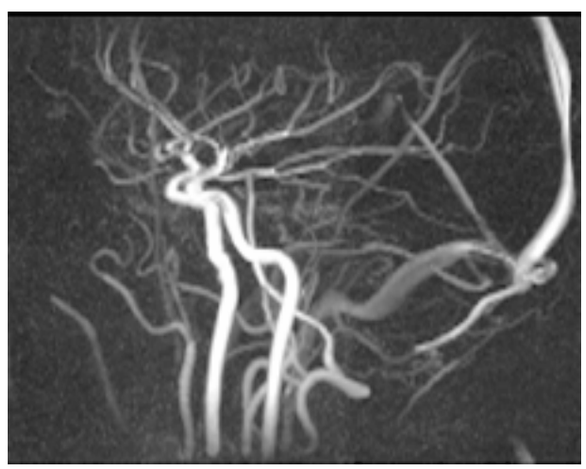
Why do we need image registration?

- Quantitatively compare scans of the same subjects done at different times or with different modalities:
  - Compare MR/CT/PET/SPECT.
  - Pre-/Post- surgery/treatment.
  - Correct for patient motion in dynamic imaging.









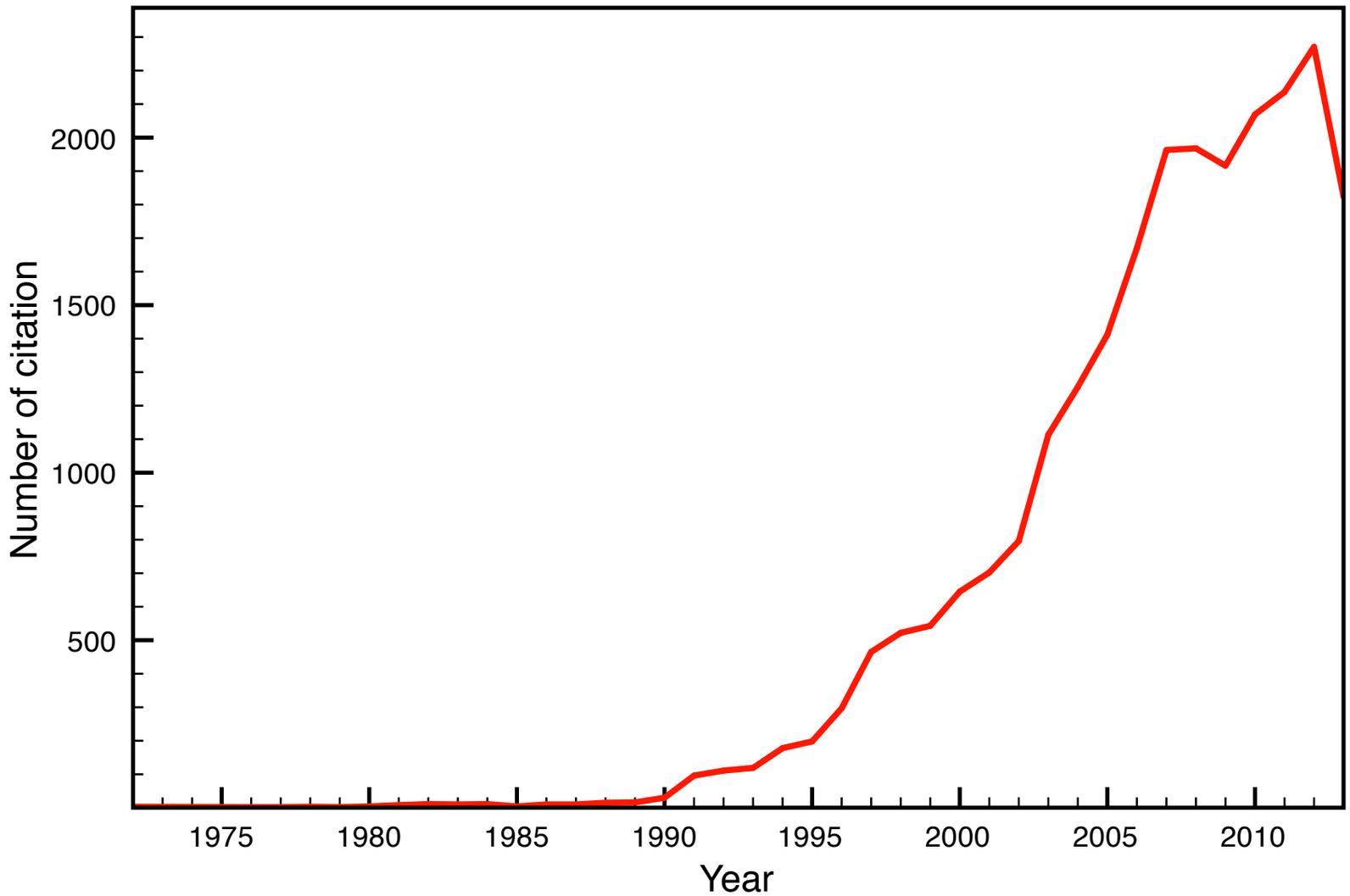
C. Ruff, D. Hawkes, 1995

Why do we need image registration?

- Quantitatively compare scans of different subjects.
  - Compare normal subjects with abnormal subjects.
  - Construct population models of anatomical variation.
  - Fit generic models to individual subjects.

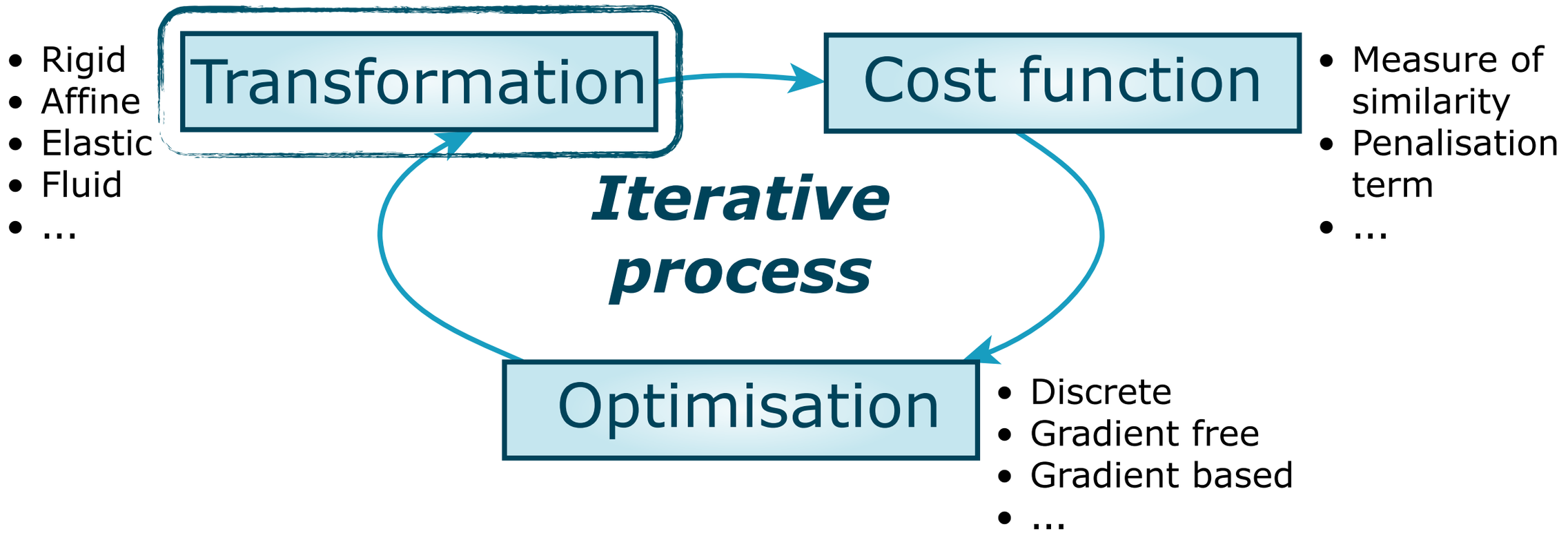
Continuing academic interest

- Number of citation per year
  - Searched for "image registration" in Web of Knowledge



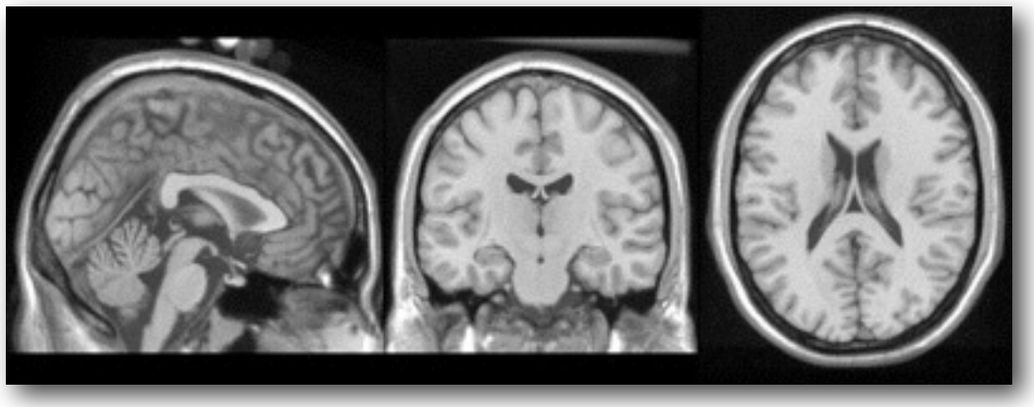
Medical image registration

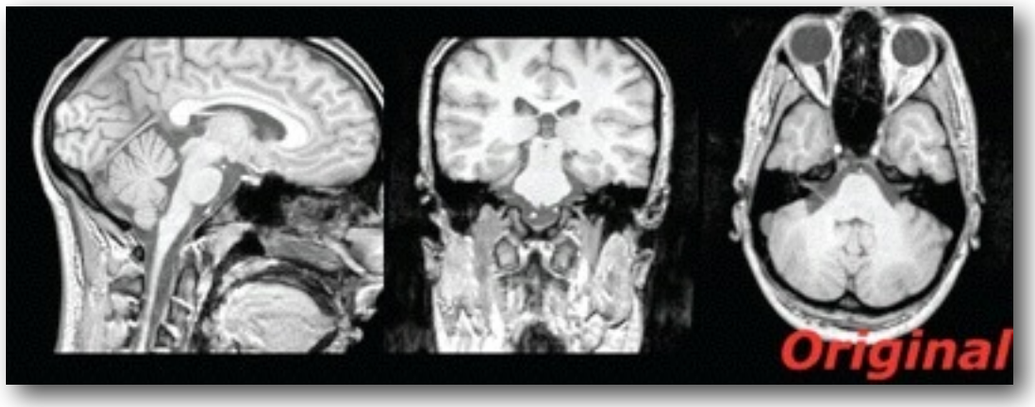
- Overall scheme

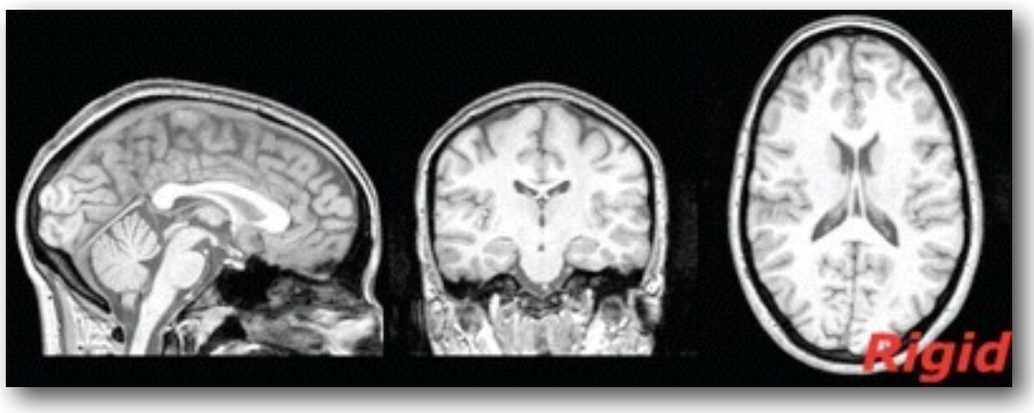


Transformation

- From rigid to non-parametric
  - increasing number of DOFs





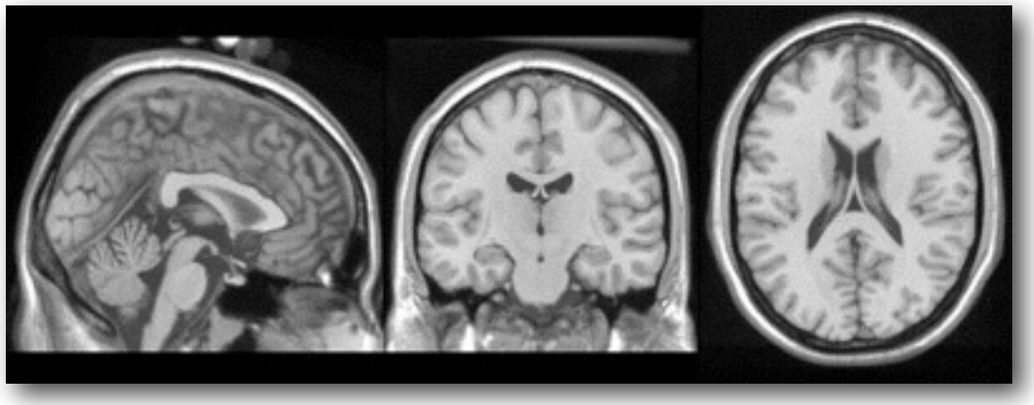


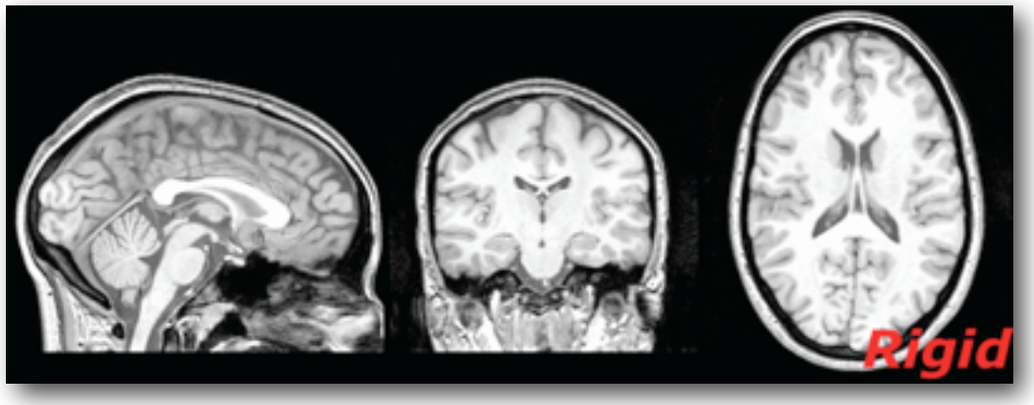
Rigid transformation: 6 DOFs

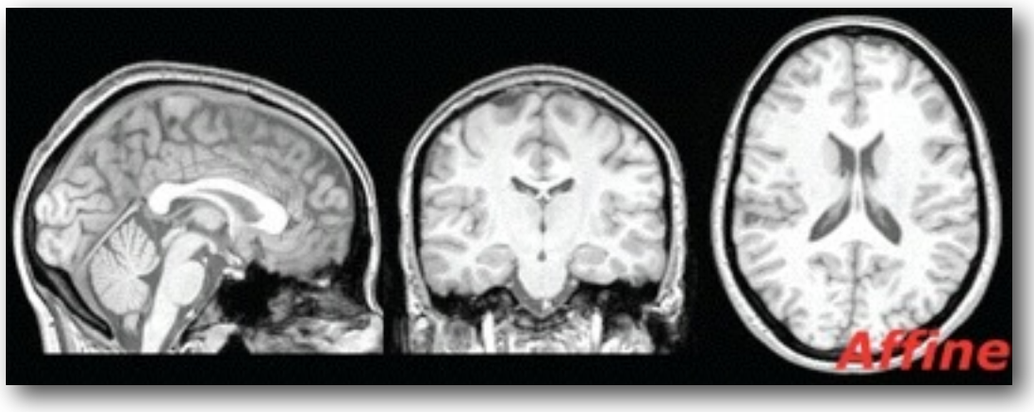
- 3 translations
- 3 rotations

Transformation

- From rigid to non-parametric
  - increasing number of DOFs



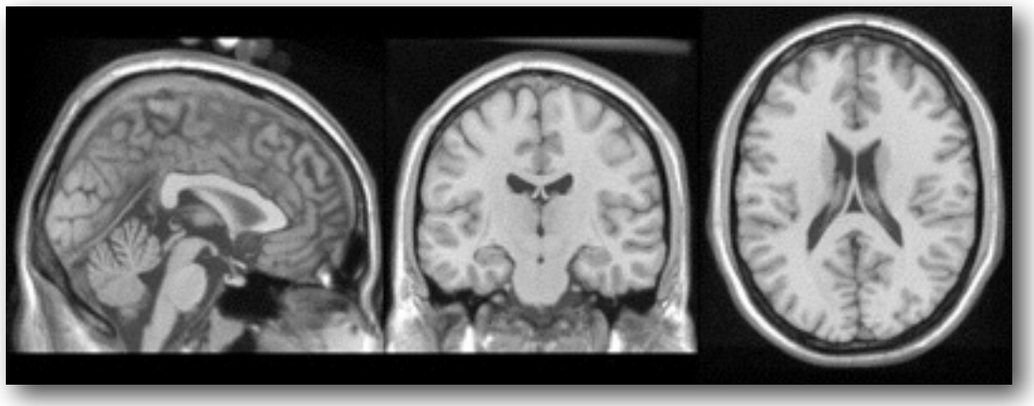


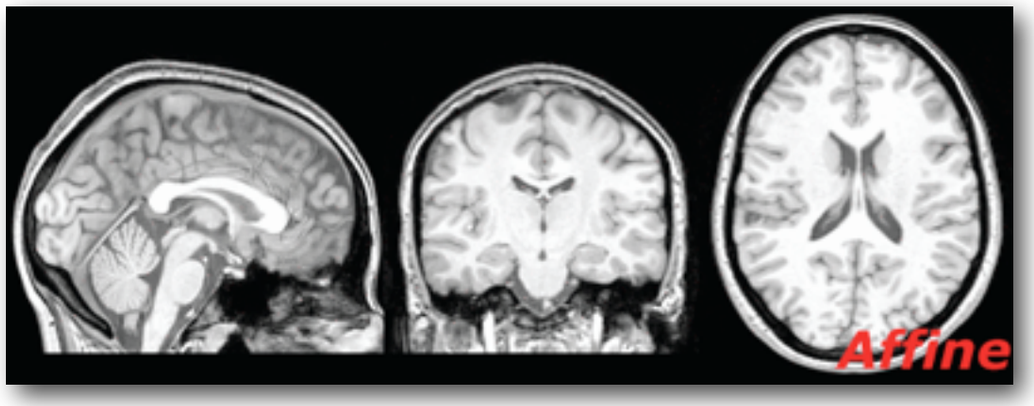


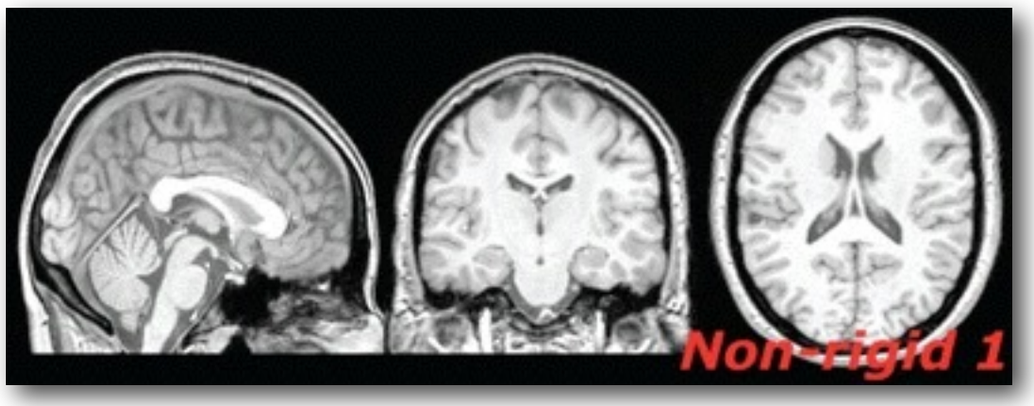
Affine transformation: 12 DOFs
- 3 translations
- 3 rotations
- 3 scalings
- 3 shearings

Transformation

- From rigid to non-parametric
  - increasing number of DOFs





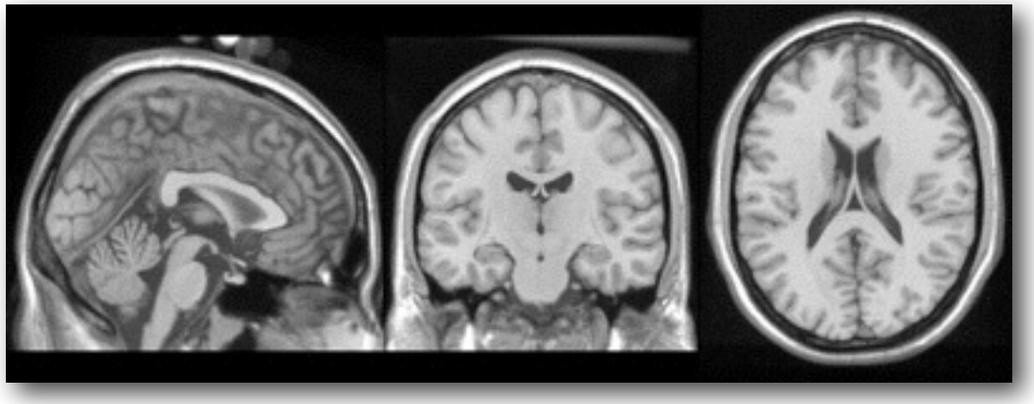


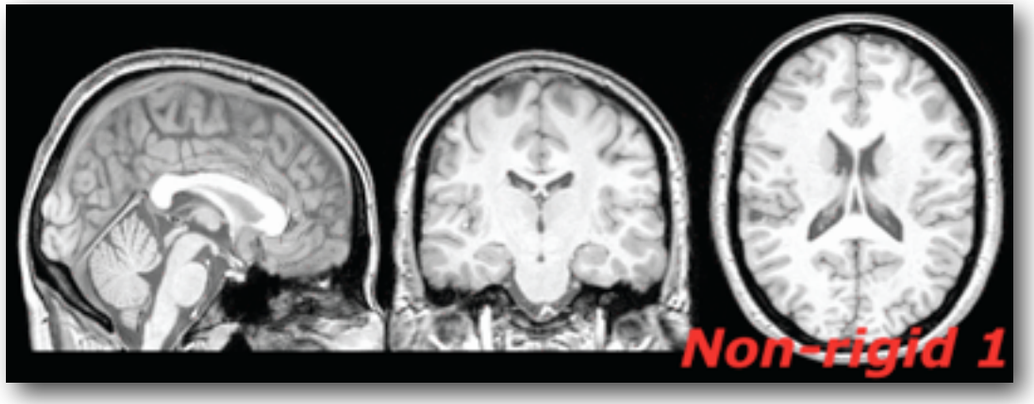
Non-rigid transformation:

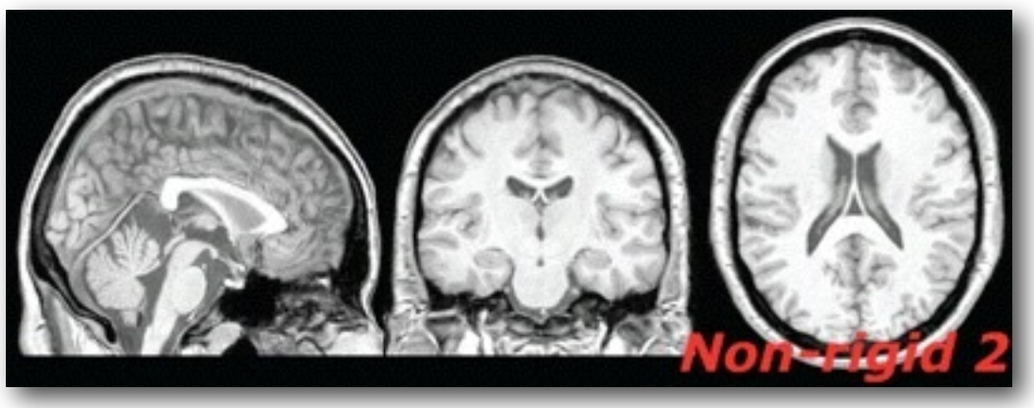
- Low number of DOFs (e.g. 300)

Transformation

- From rigid to non-parametric
  - increasing number of DOFs







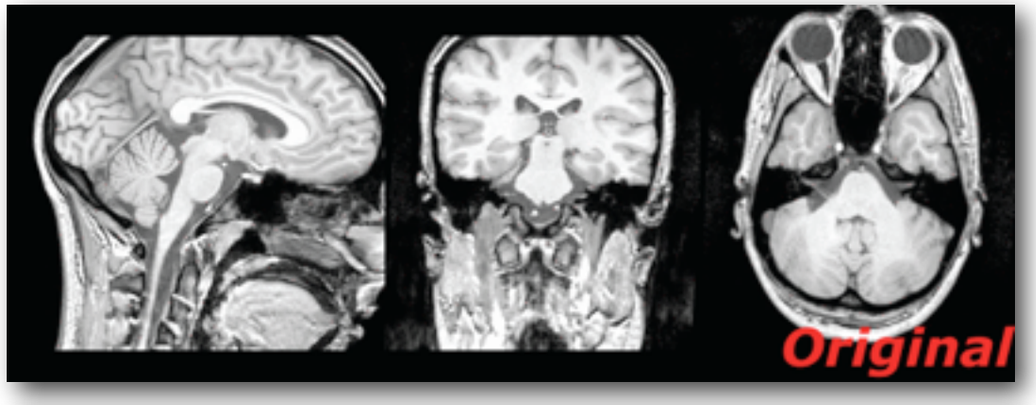
Non-rigid transformation:

- Higher number of DOFs (e.g. >500.000)

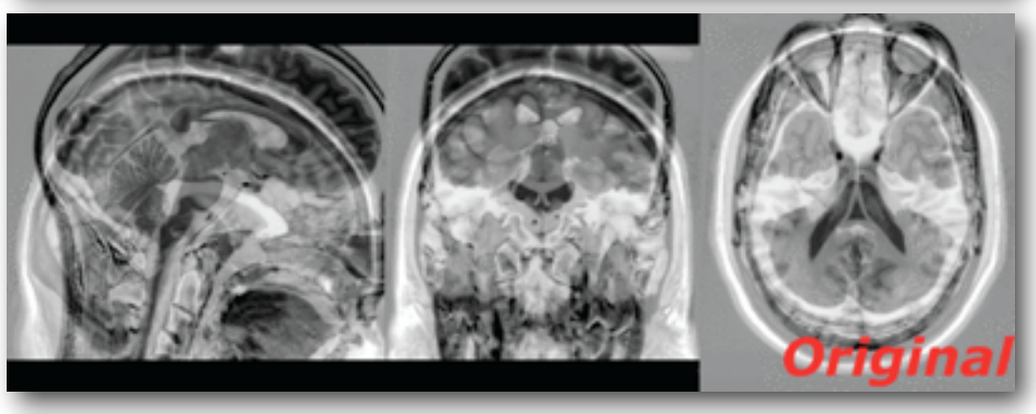
Transformation

- From rigid to non-parametric
  - increasing number of DOFs

Warped images



Difference images



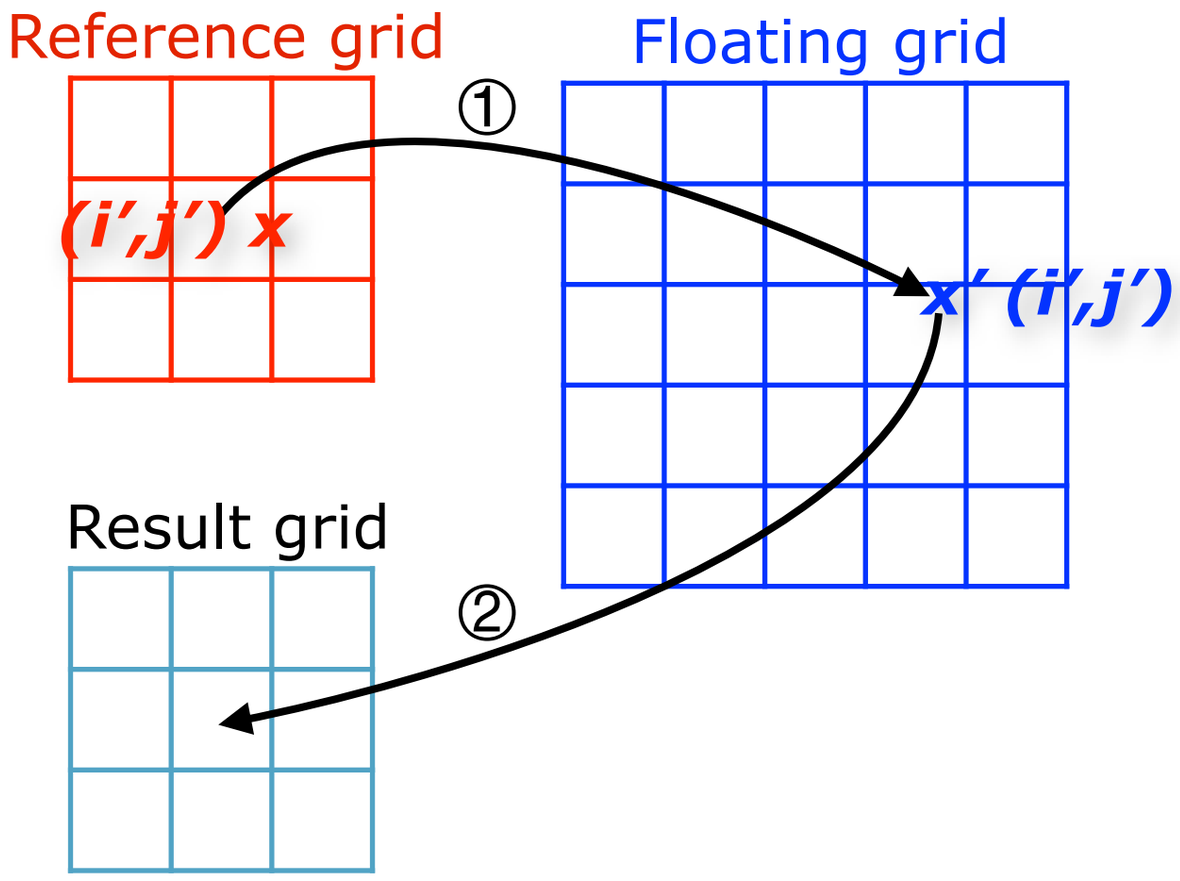
Expansion / compression maps
(Jacobian maps)

Transformation

- Resampling

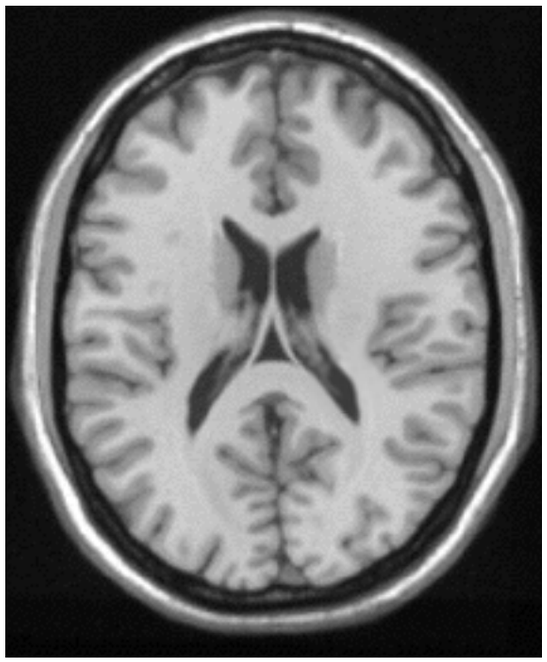
① For each pixel with coordinate ***(i,j)*** in the reference image, we know the corresponding position ***(i′,j′)***in the floating image.

② In order to deform the floating image, the intensity at position ***(i′,j′)*** is evaluated using resampling technique and displayed in the result image.

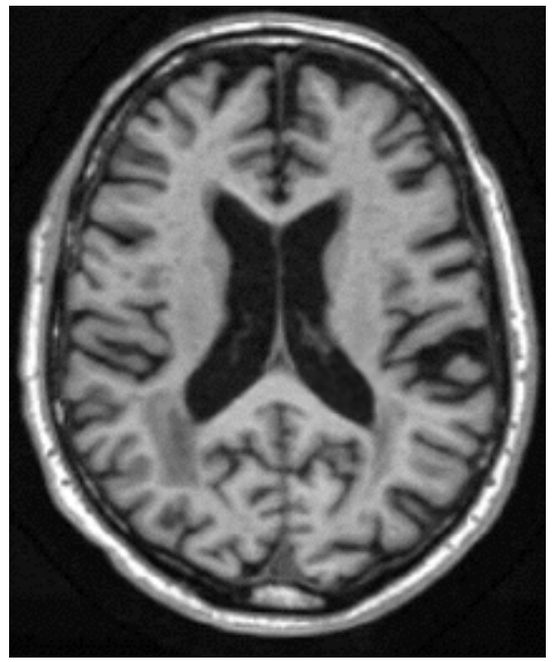


Transformation

- Resampling



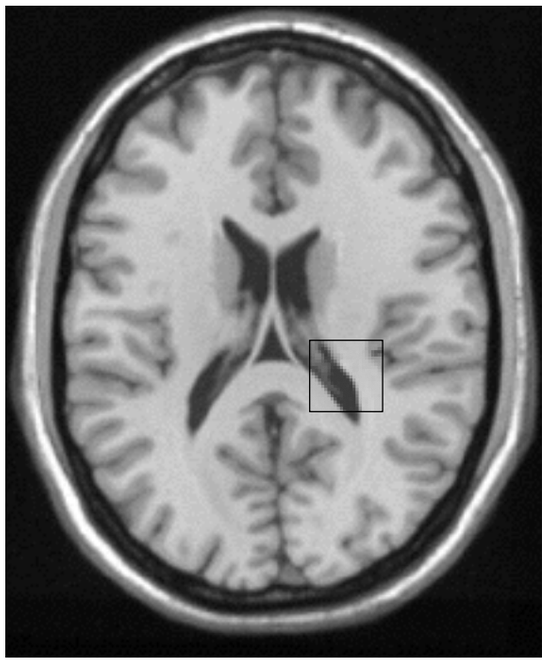
Reference image

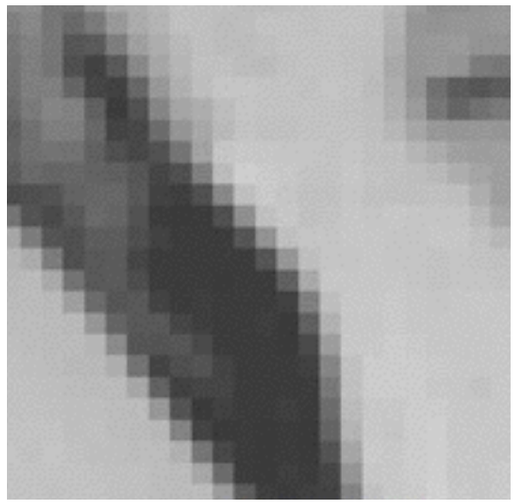


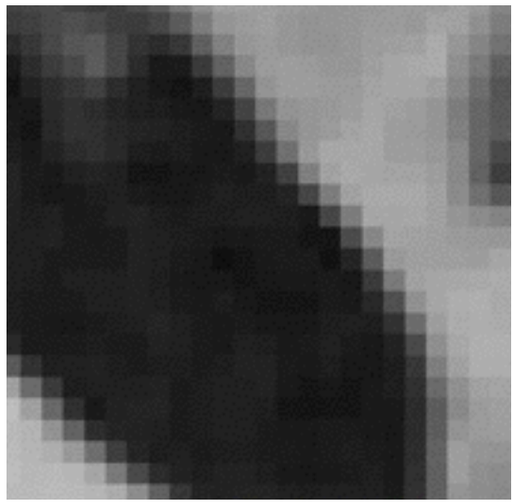
Floating image

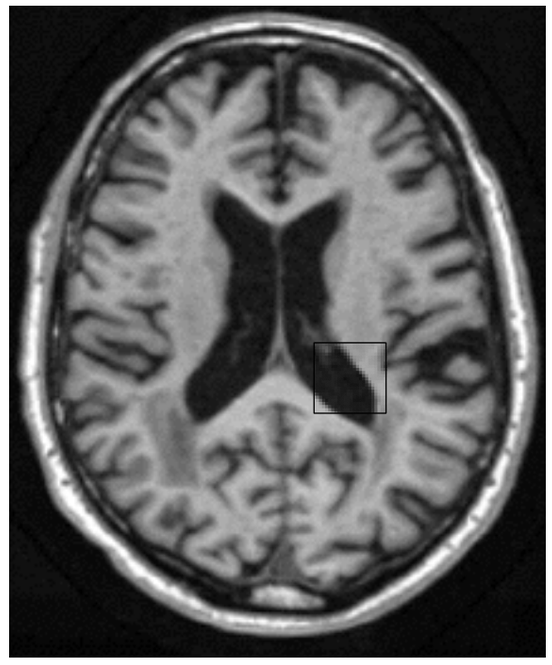
Transformation

- Resampling

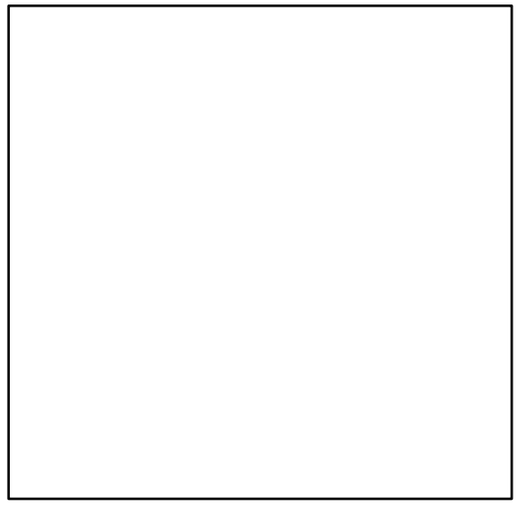








Reference image

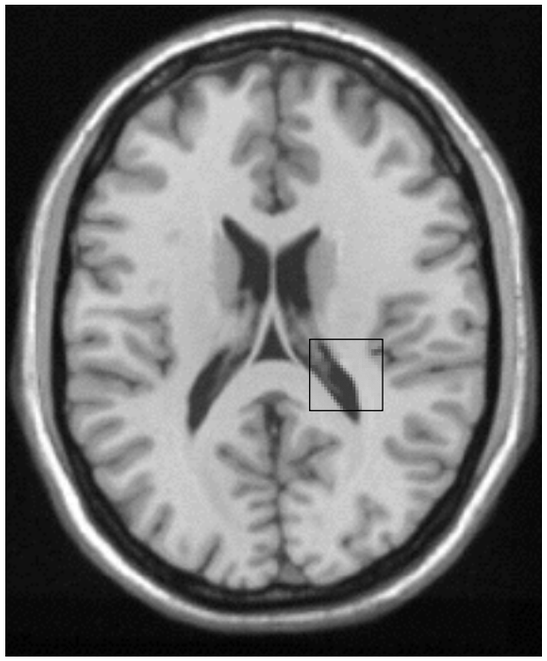


Warped floating image

Floating image

Transformation

- Resampling



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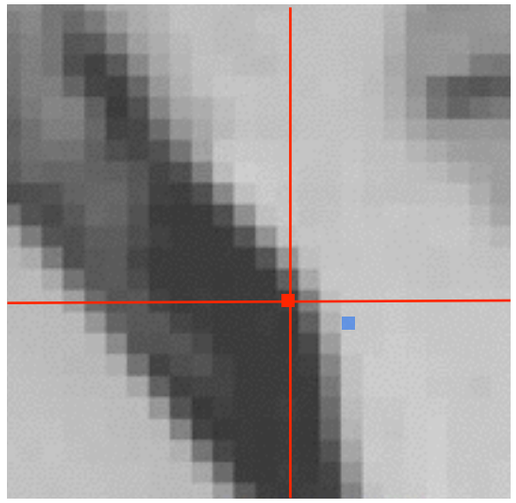
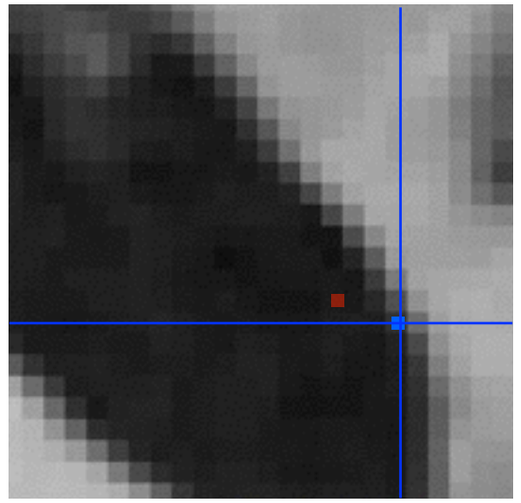
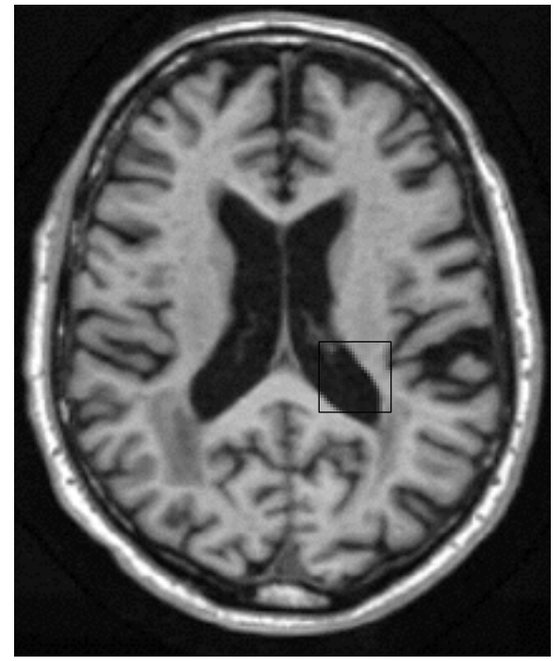
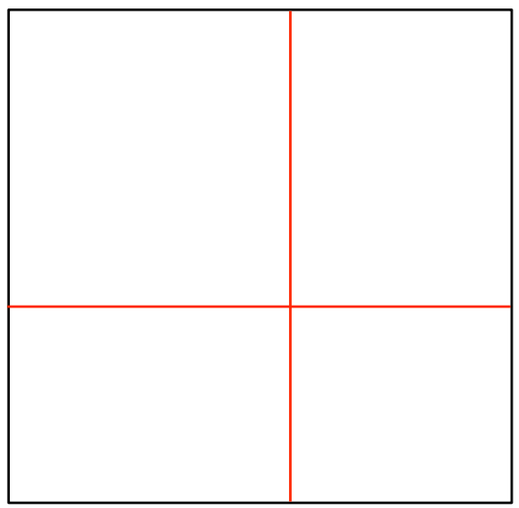






Floating image



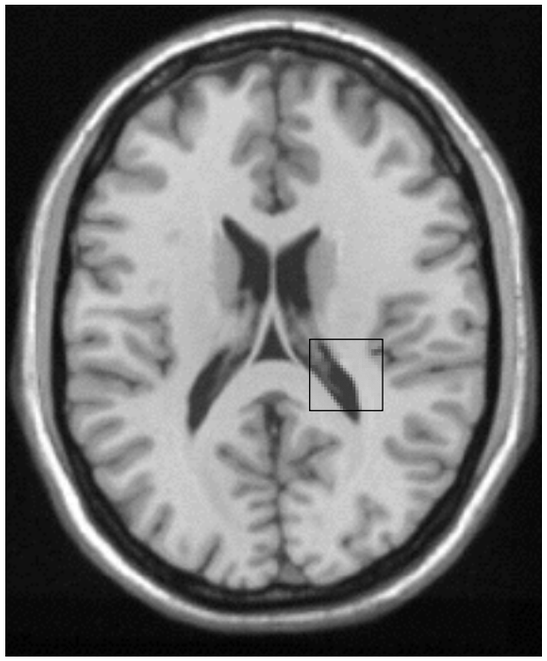
Warped floating image

$$\mathbf{T}(\vec{x}) = \vec{x}'$$

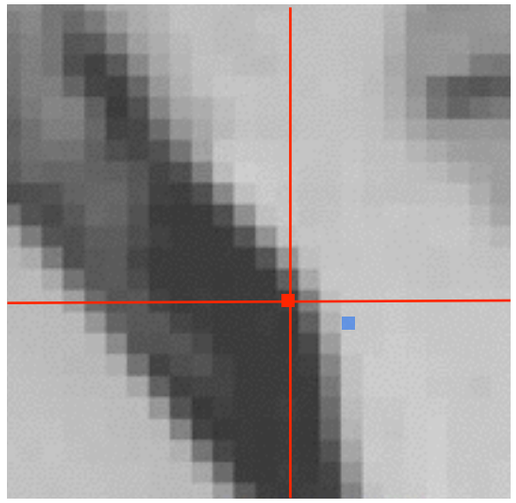
$$\mathbf{T}(\vec{x}) = \vec{x} + \begin{vmatrix} t_x \\ t_y \end{vmatrix}$$

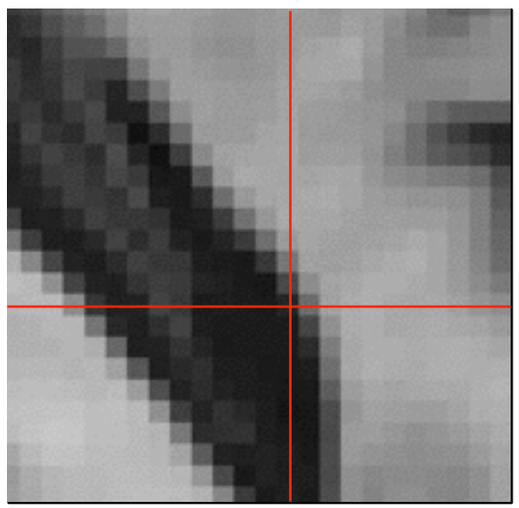
Transformation

- Resampling

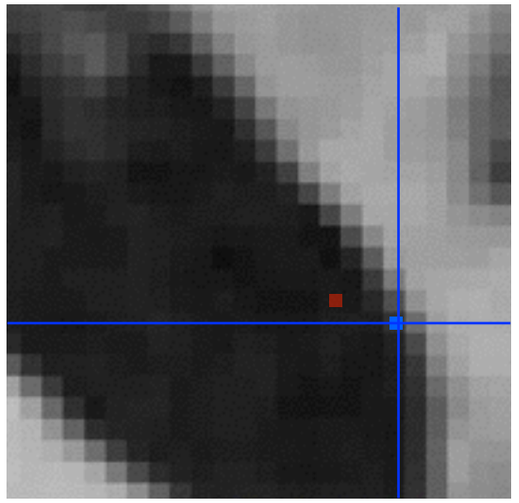


Reference image



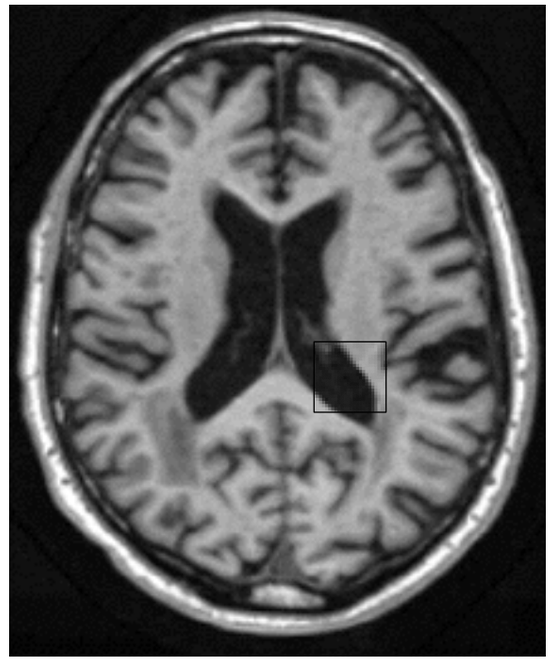


Warped floating image



$$\mathbf{T}(\vec{x}) = \vec{x}'$$

$$\mathbf{T}(\vec{x}) = \vec{x} + \begin{vmatrix} t_x \\ t_y \end{vmatrix}$$



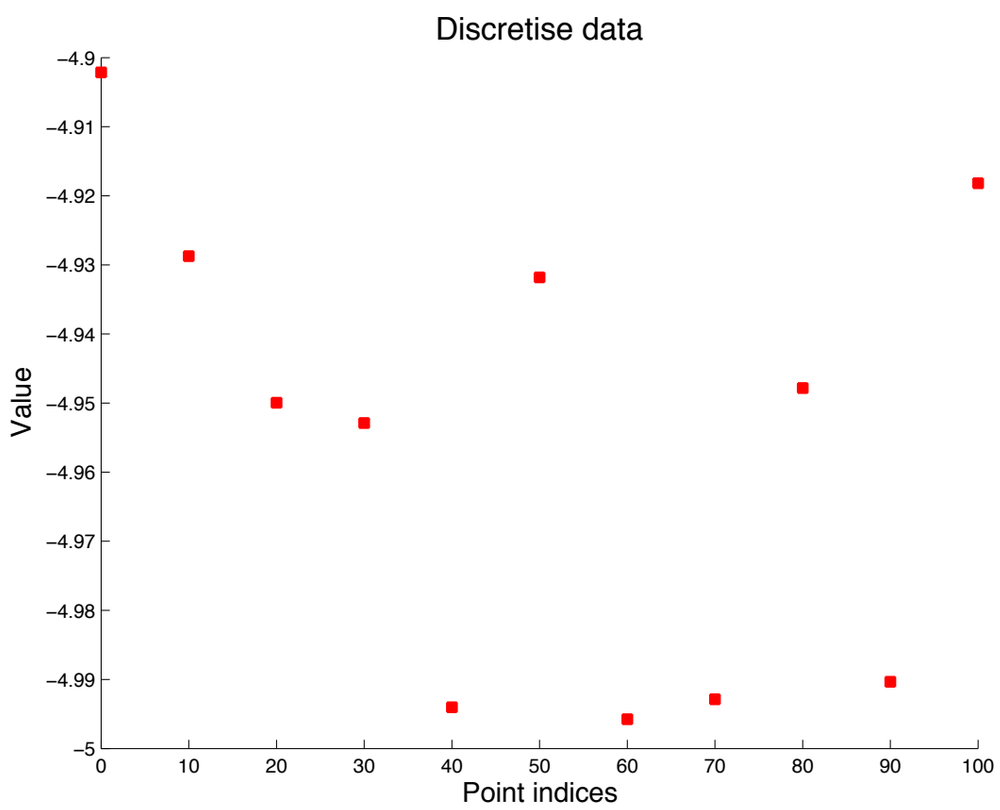
Floating image

Transformation

- Resampling
  - The recovered transformation does not necessarily fold into an integer position

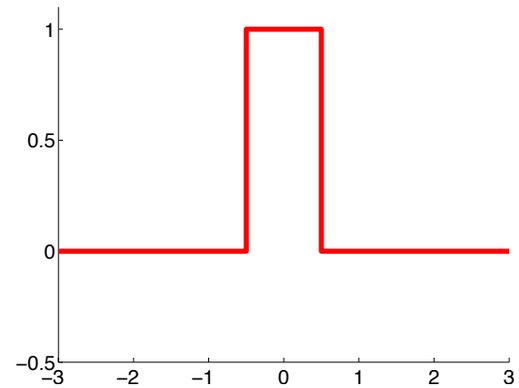
Transformation

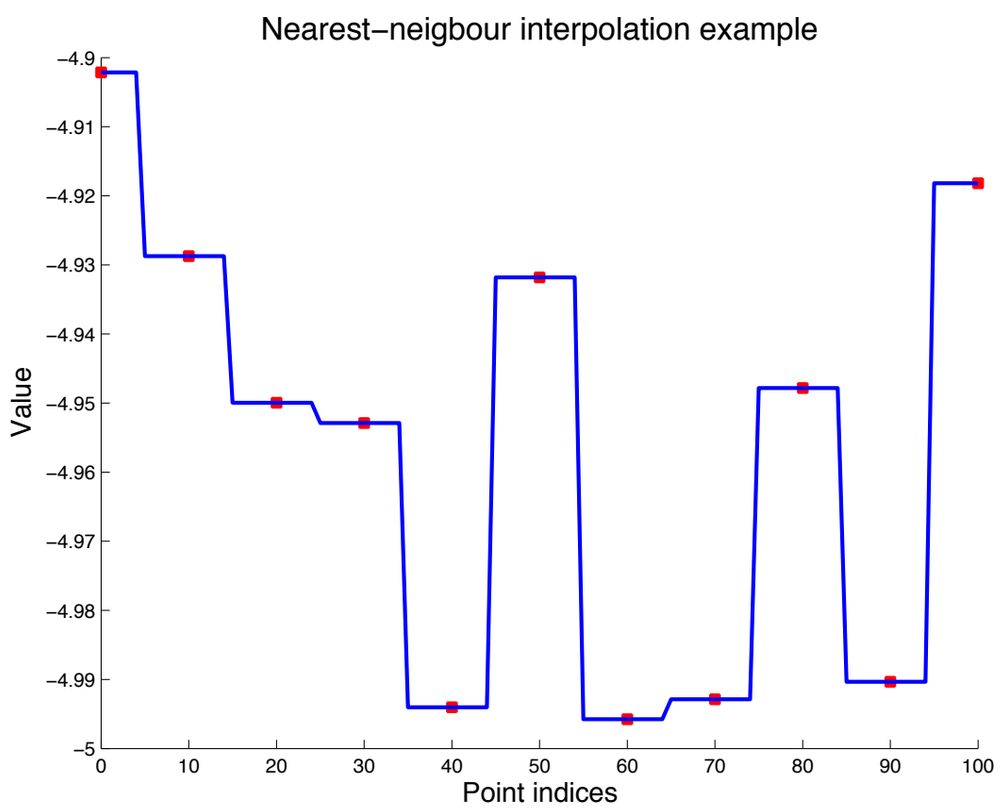
- Resampling
  - Various interpolation techniques
    - Nearest neighbor (0^{th} order)
    - Linear interpolation (1^{st} order)
    - Cubic interpolation (3^{th} order)



Transformation

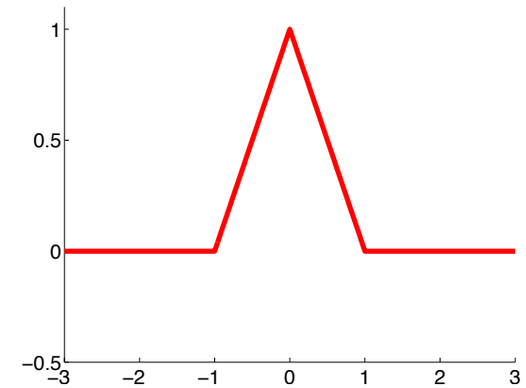
- Resampling
  - Various interpolation techniques
    - Nearest neighbor (0th order)
    - Linear interpolation (1st order)
    - Cubic interpolation (3th order)

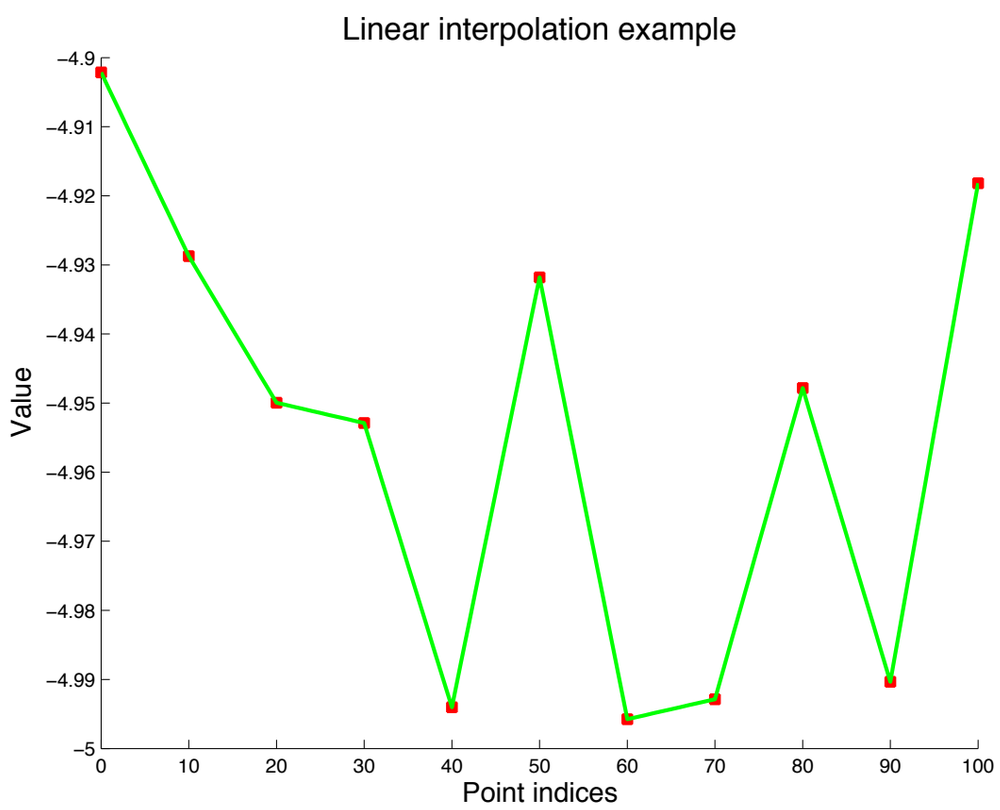




Transformation

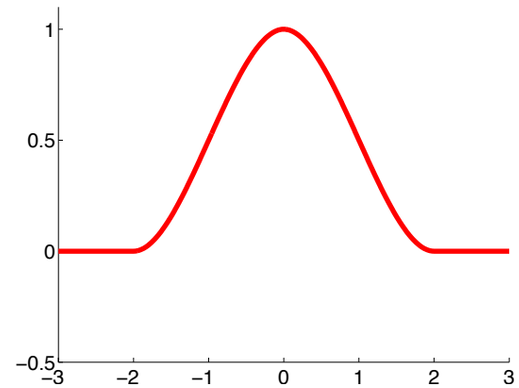
- Resampling
  - Various interpolation techniques
    - Nearest neighbor (0th order)
    - Linear interpolation (1st order)
    - Cubic interpolation (3th order)

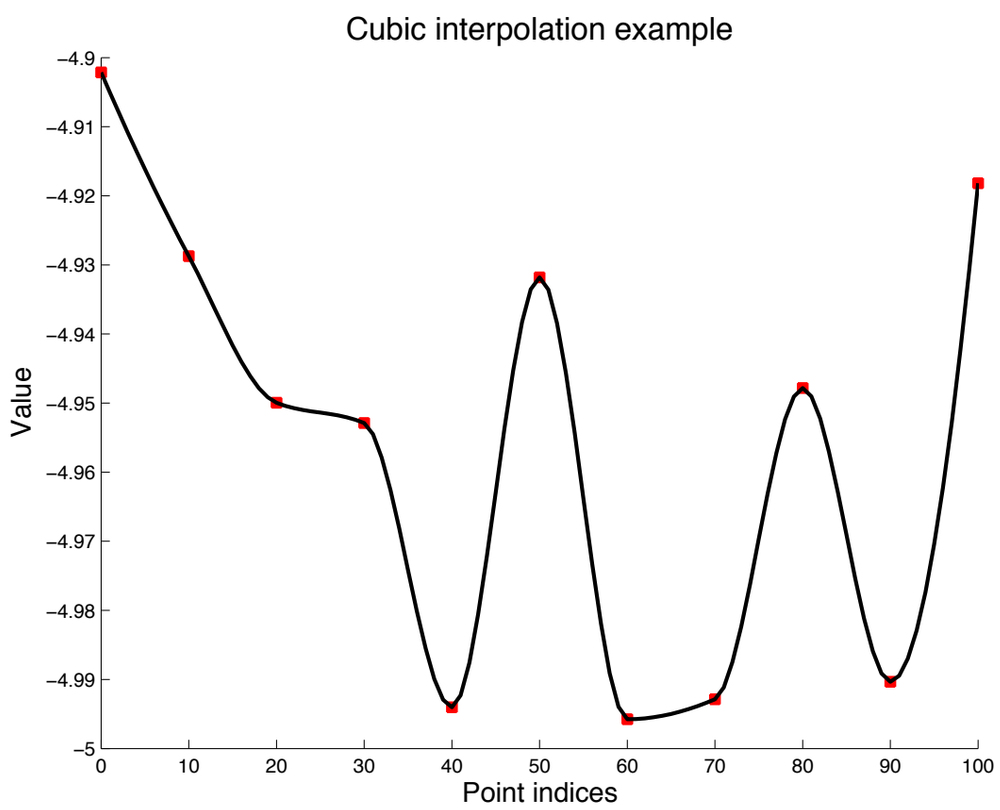




Transformation

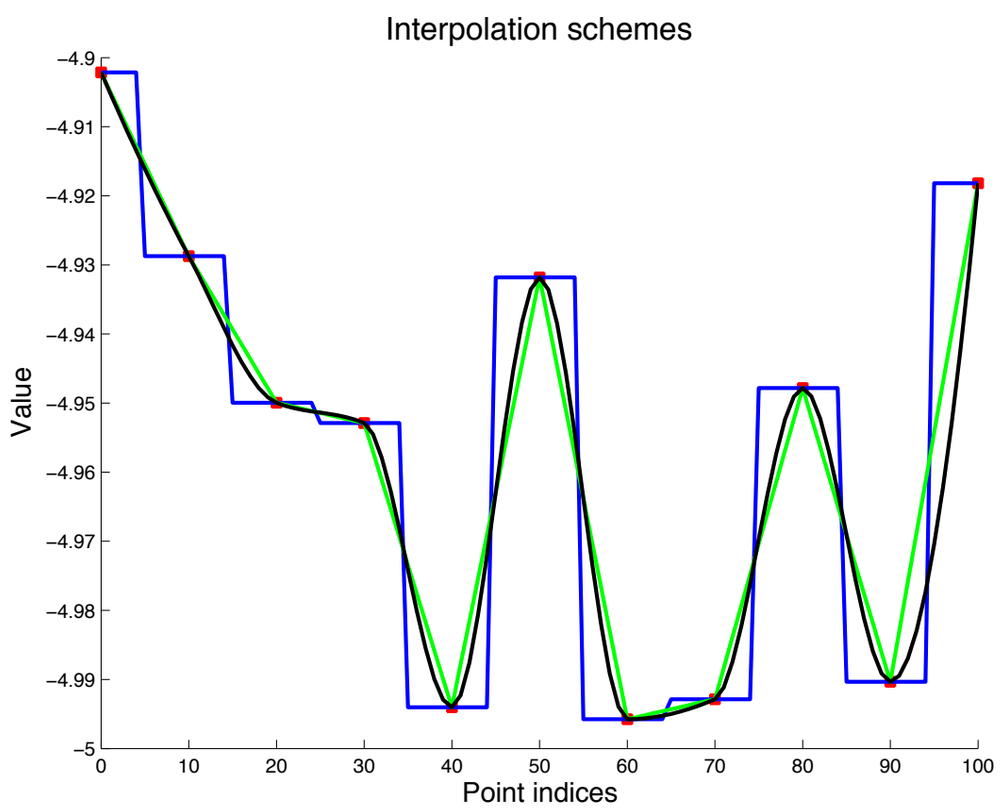
- Resampling
  - Various interpolation techniques
    - Nearest neighbor (0th order)
    - Linear interpolation (1st order)
    - Cubic interpolation (3th order)





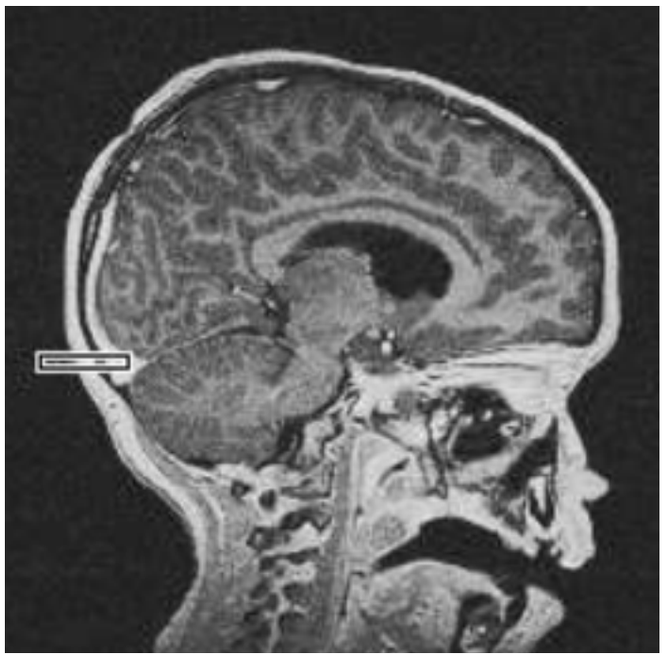
Transformation

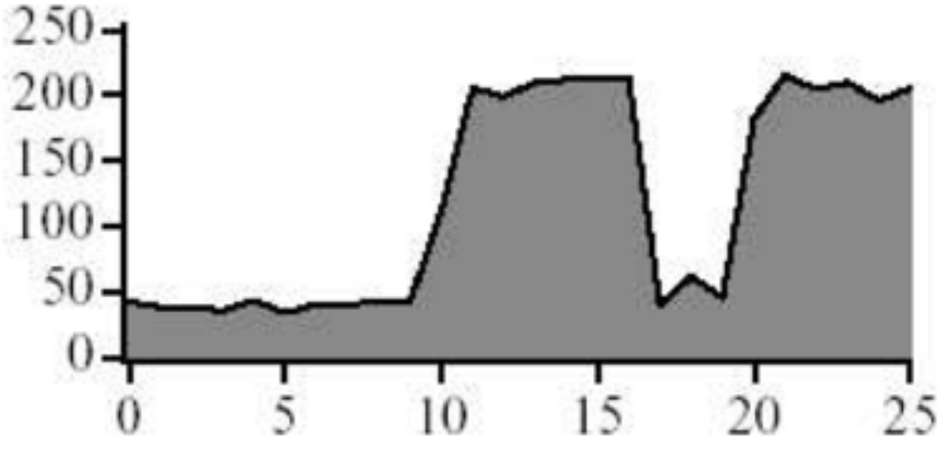
- Resampling
  - Various interpolation techniques
    - Nearest neighbor (0th order)
    - Linear interpolation (1st order)
    - Cubic Spline interpolation (3th order)

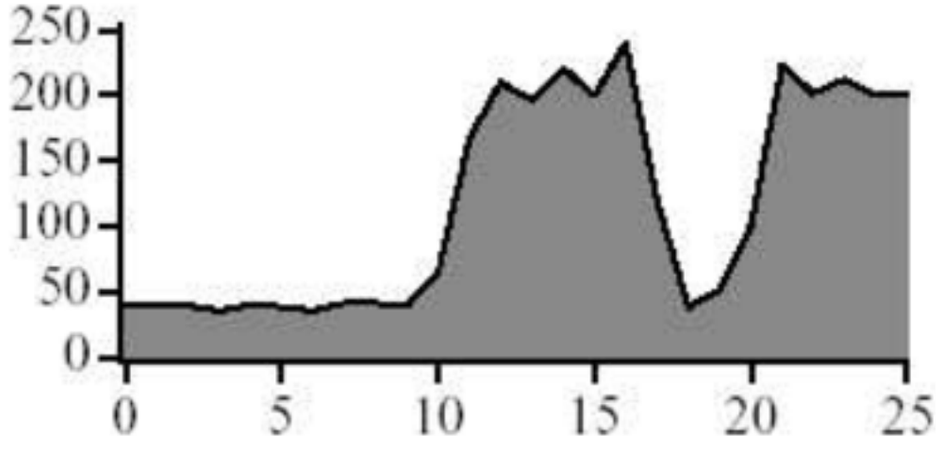


Transformation

- Resampling artefact
  - Ringing (translation by half a pixel)

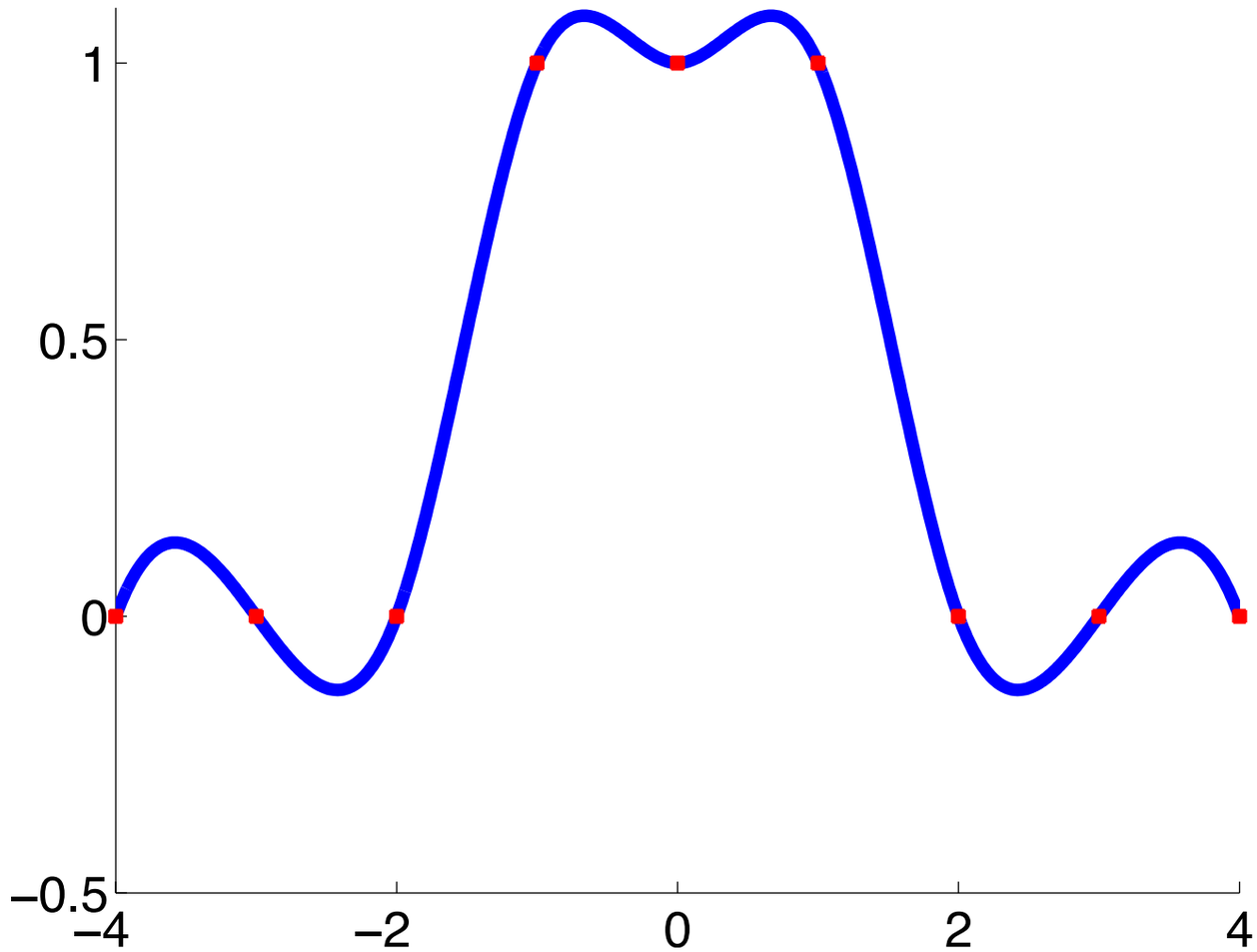






Transformation

- Resampling artefact
  - Ringing (translation by half a pixel)

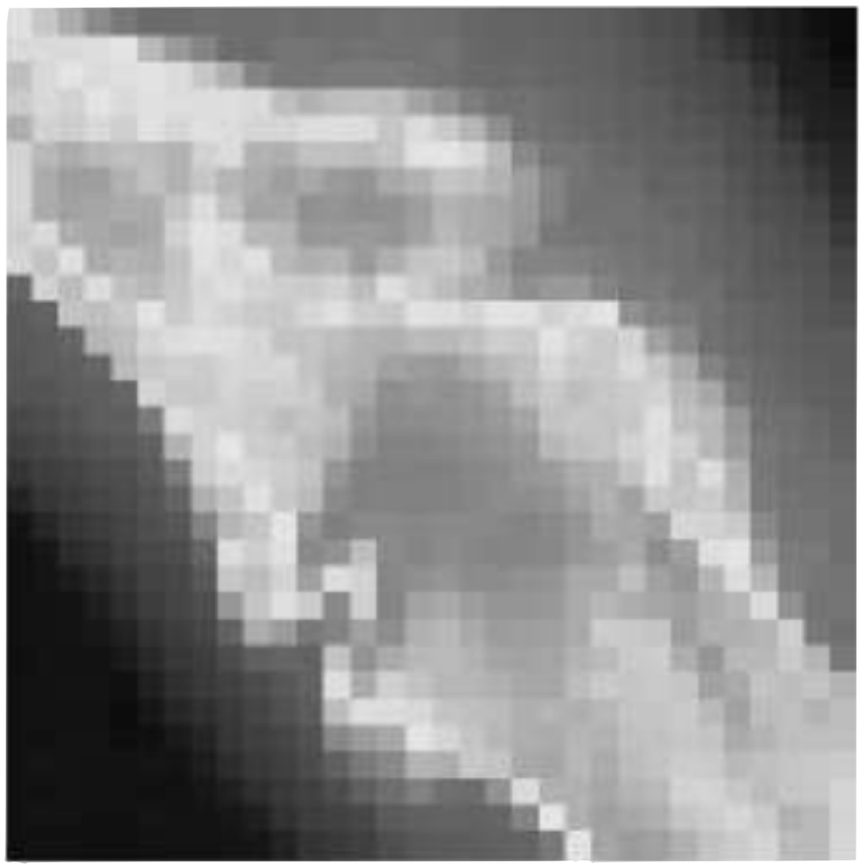


Cubic Spline interpolation

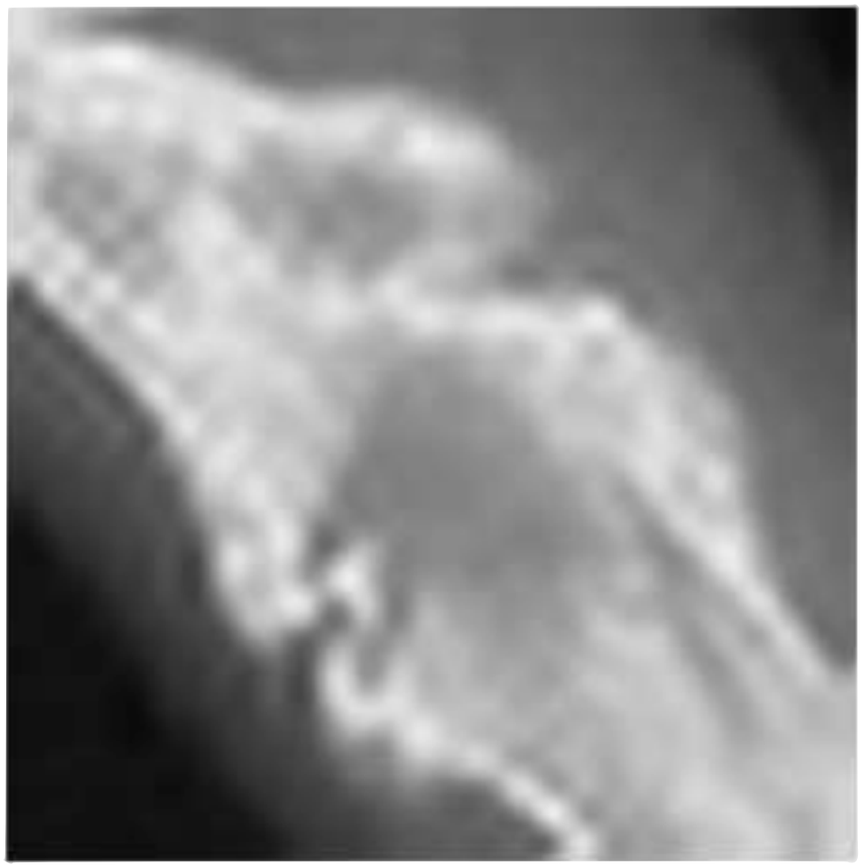
Transformation

- Resampling artefact
  - Aliasing

Original image



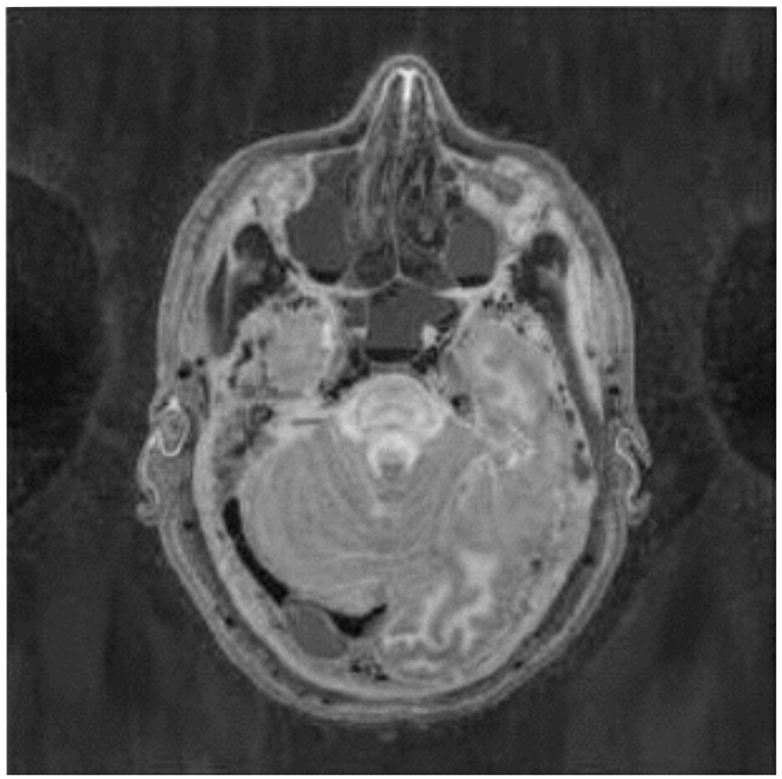
Nearest neighbor interpolation



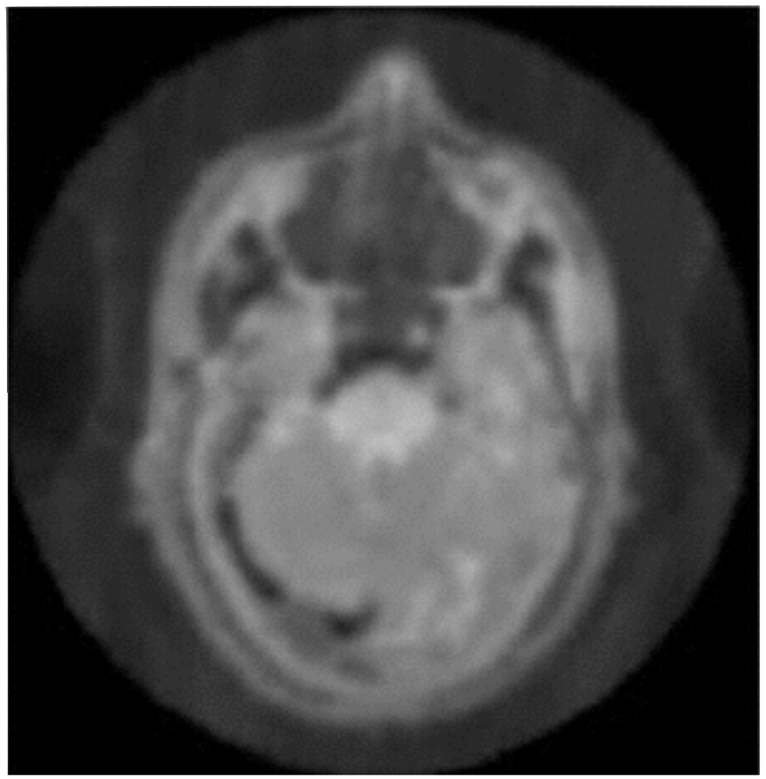
Higher order interpolation

Transformation

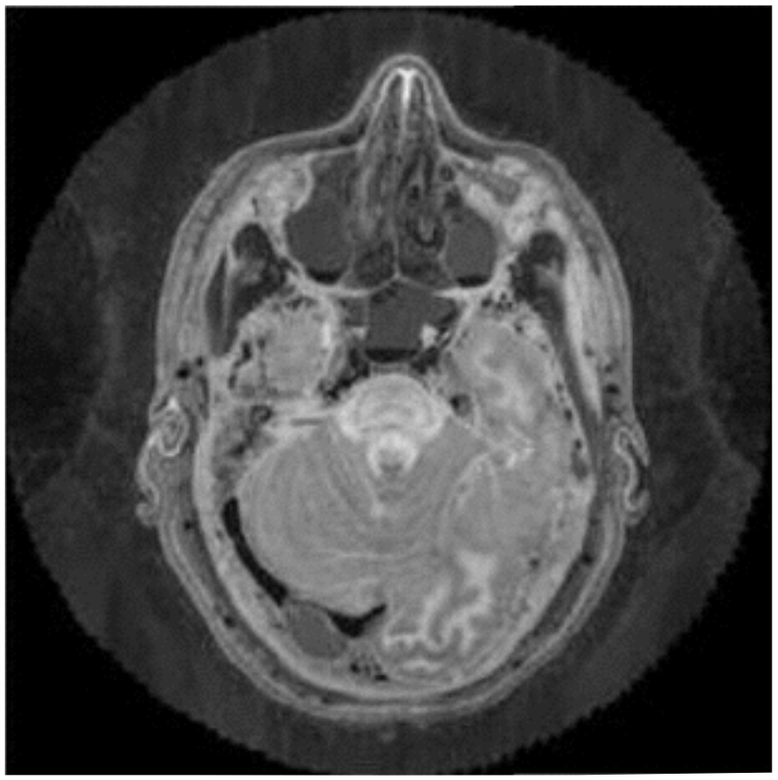
- Resampling artefact
  - Blurring (multiple rotations with different resampling order)



Original image



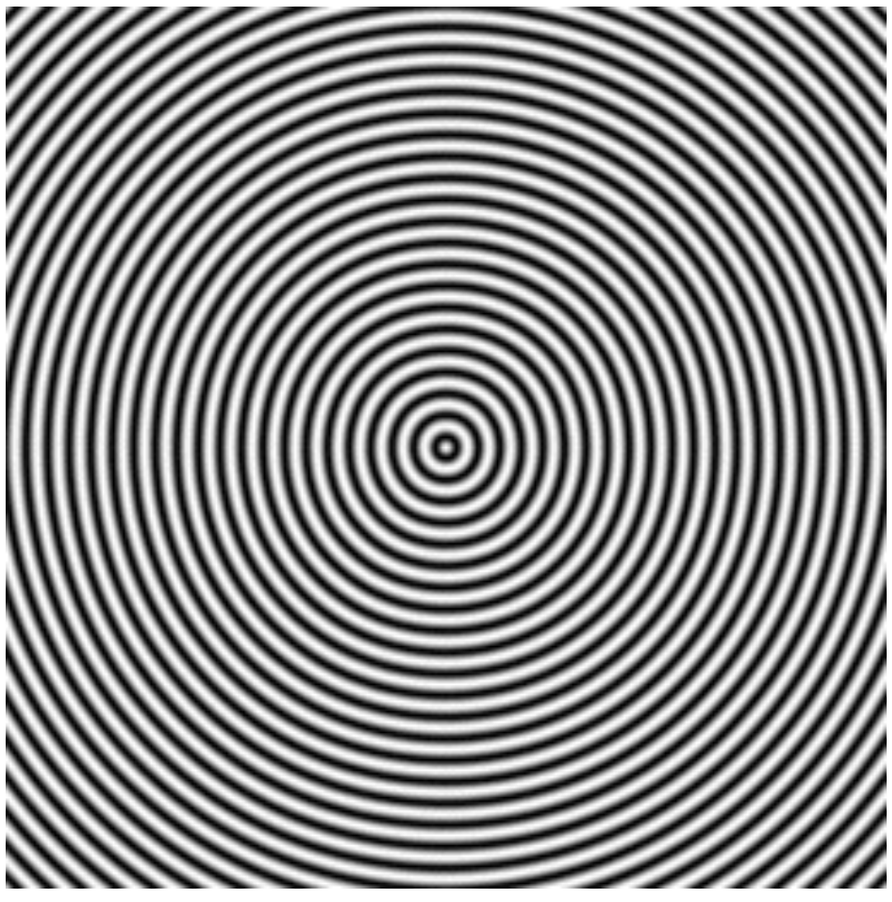
Low order interpolation



High order interpolation

Transformation

- Resampling: example

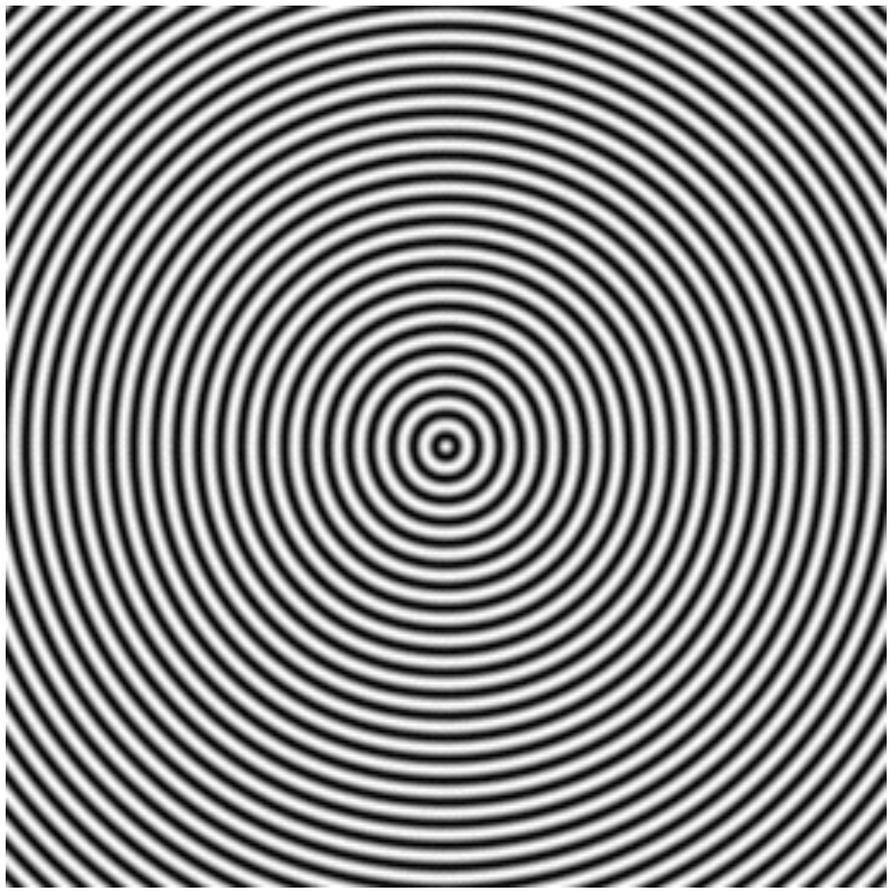


Original image

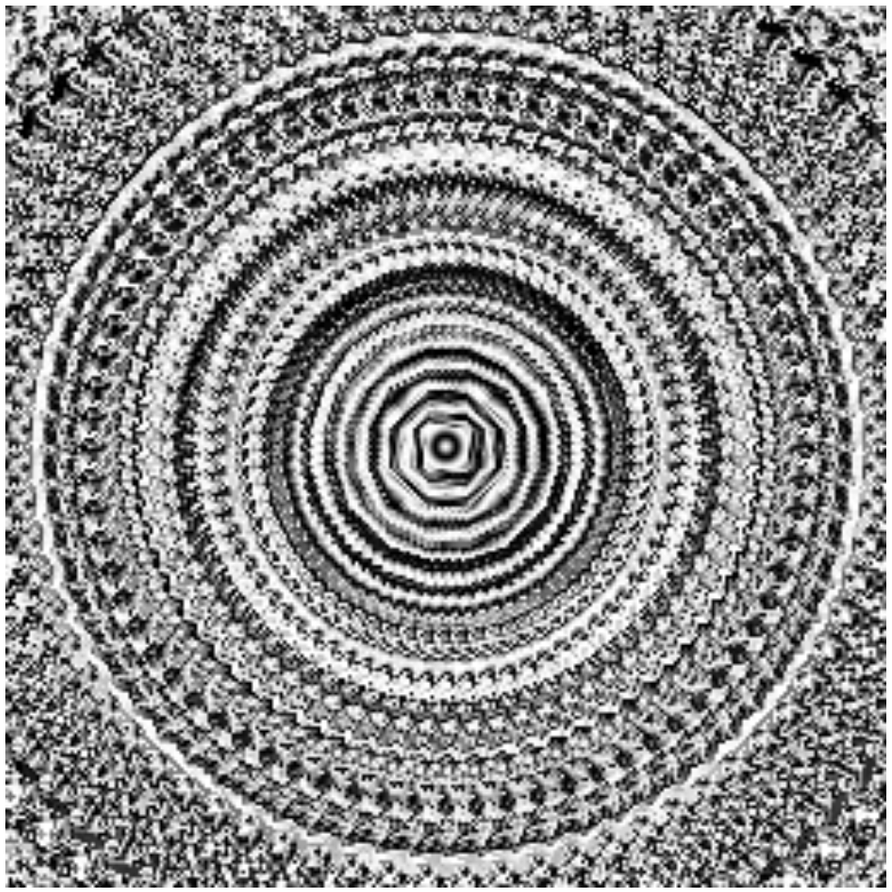
Applied 100 successive rotations of 5 degree

Transformation

- Resampling: example



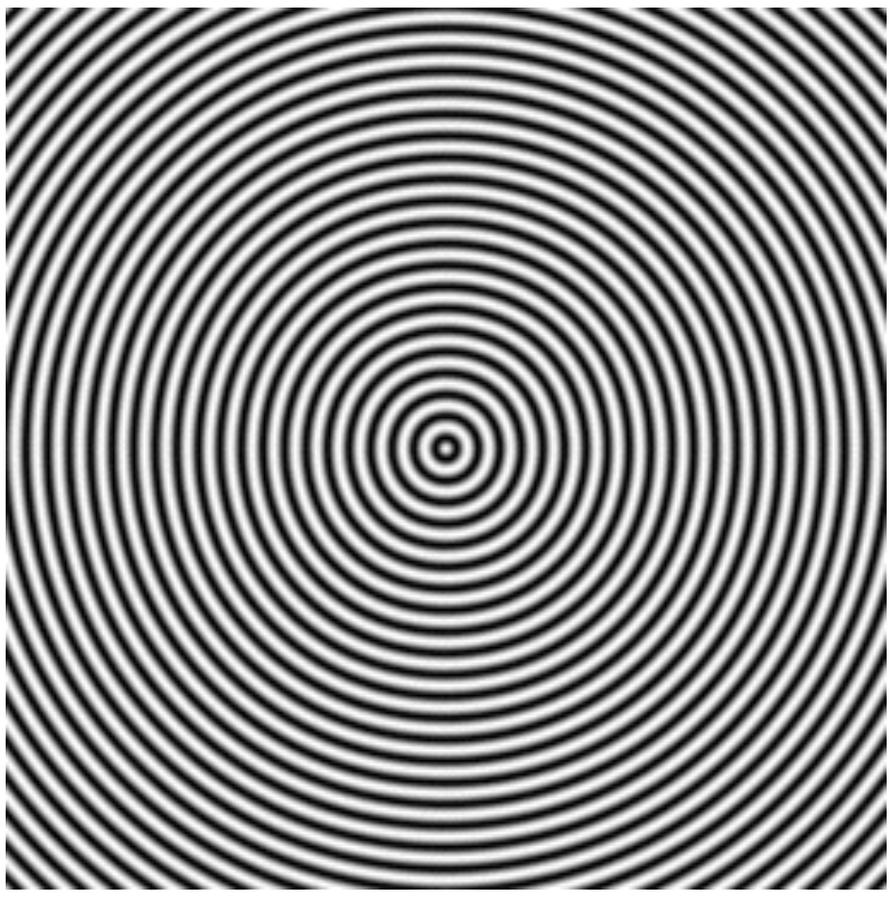
Original image



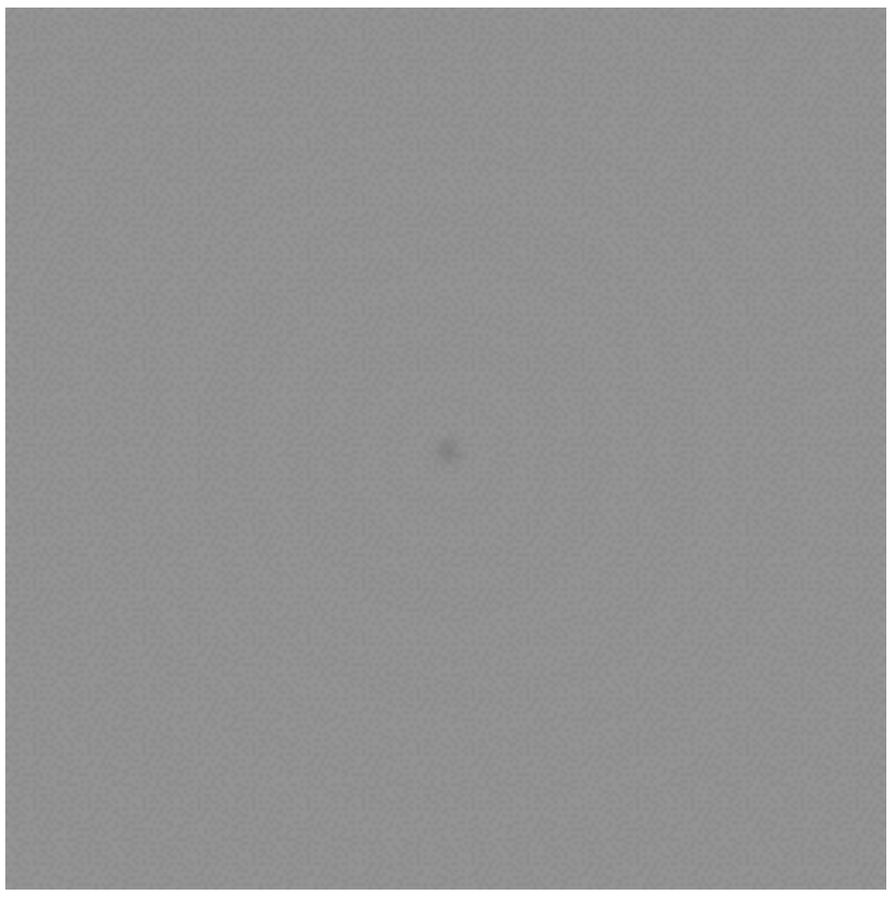
using nearest-neighbor interpolation

Transformation

- Resampling: example



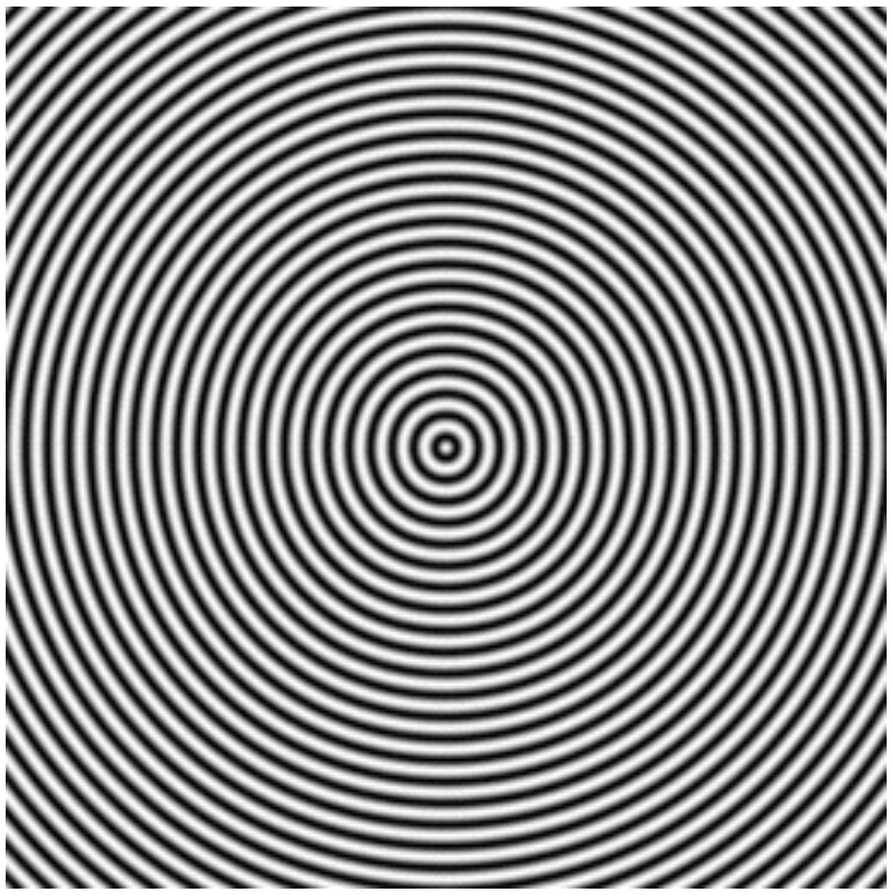
Original image



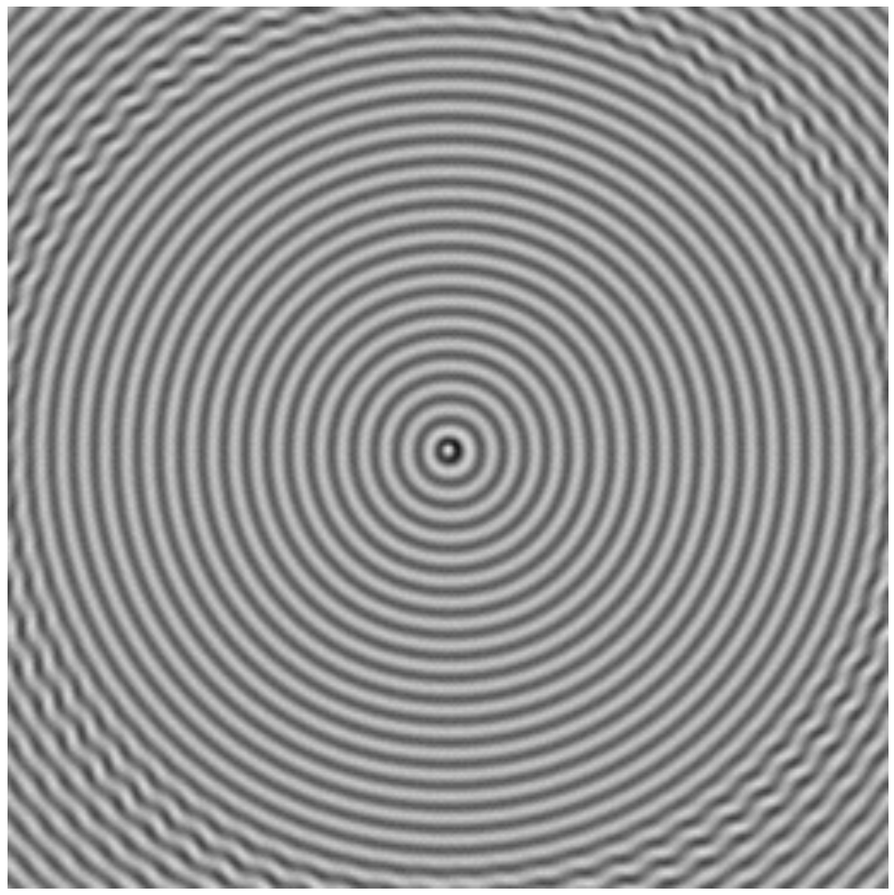
using linear interpolation

Transformation

- Resampling: example



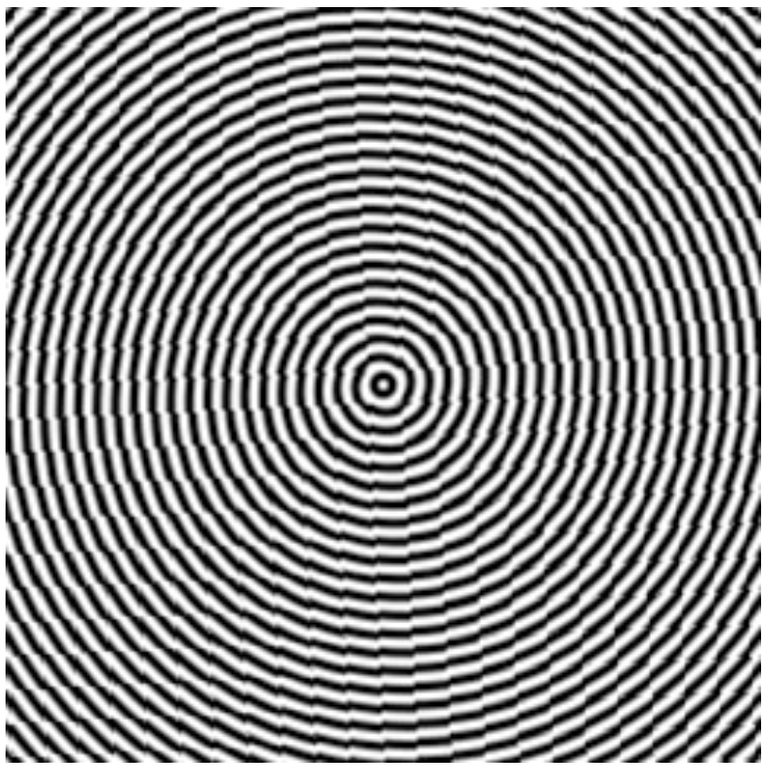
Original image



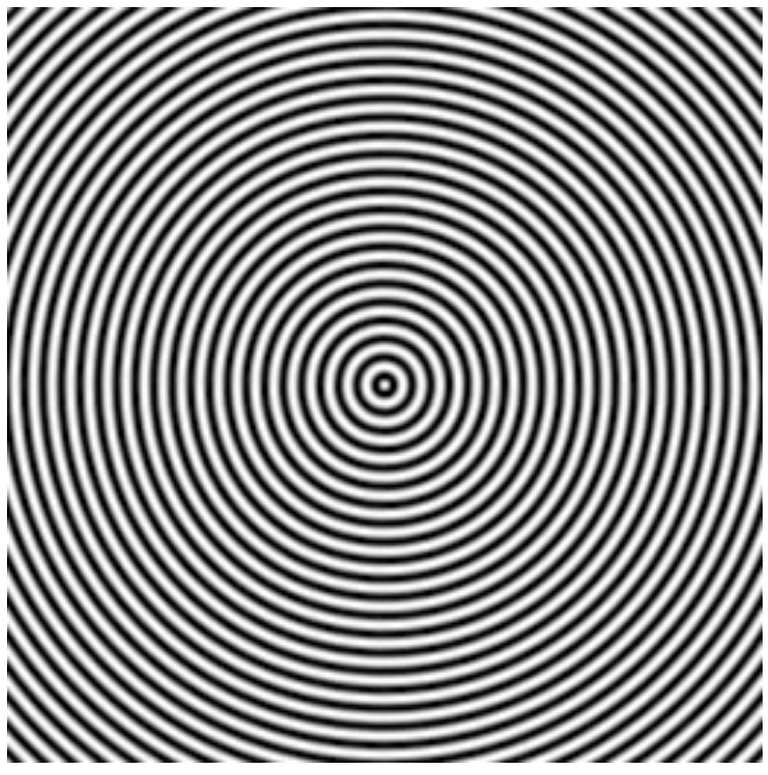
using cubic interpolation

Transformation

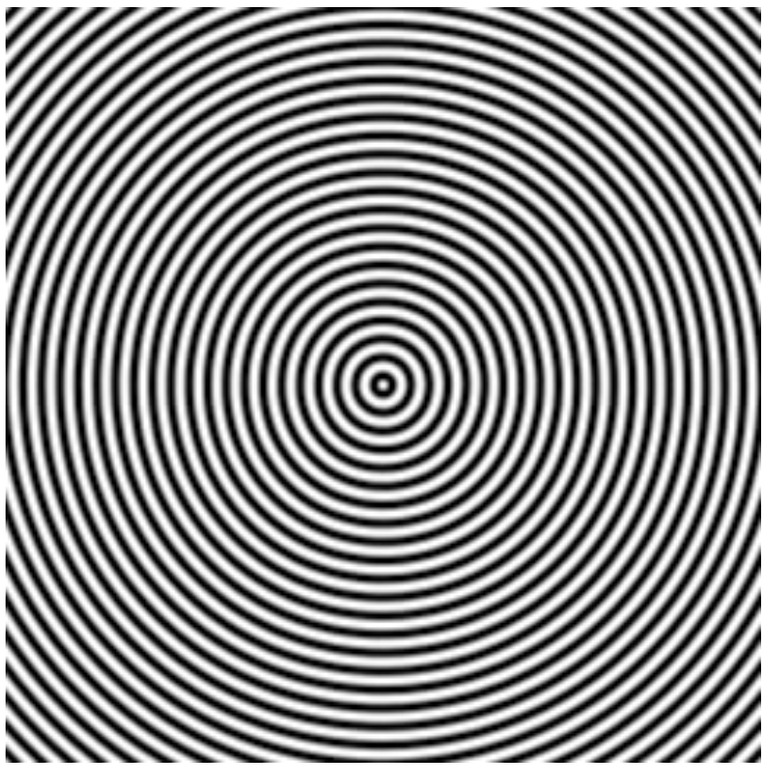
- Resampling: example



using nearest-neighbor interpolation



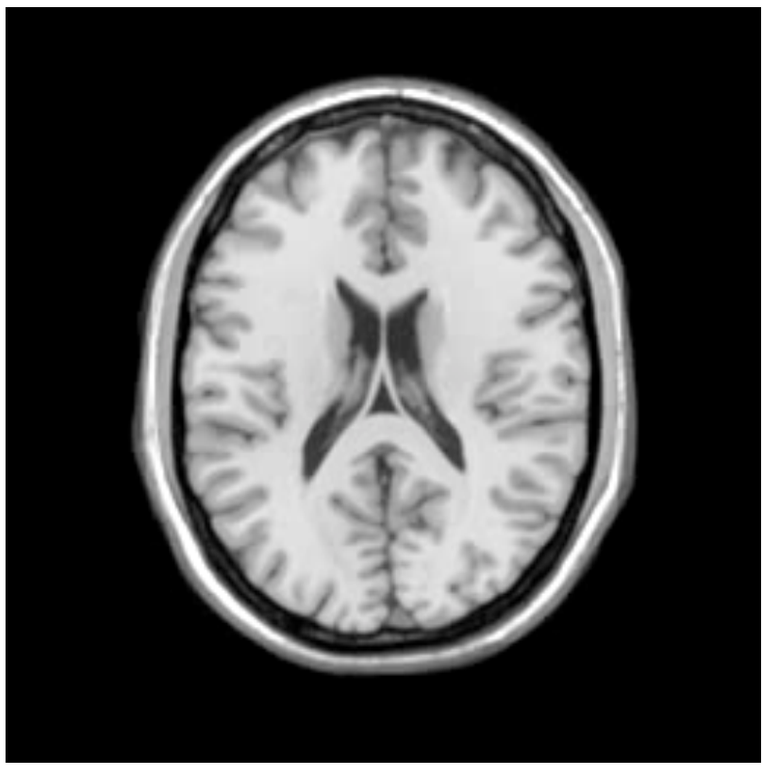
using linear interpolation



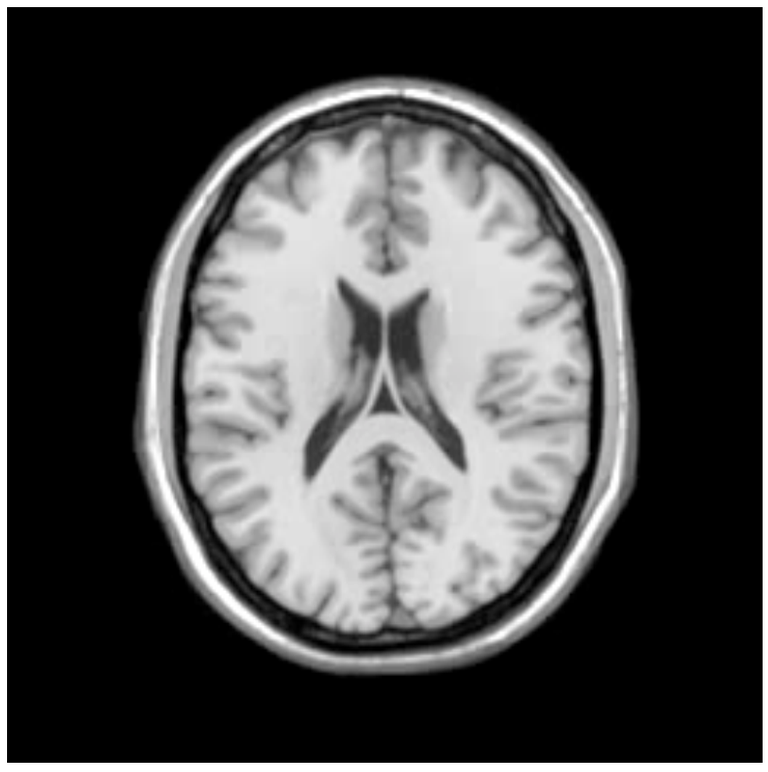
using cubic interpolation

Transformation

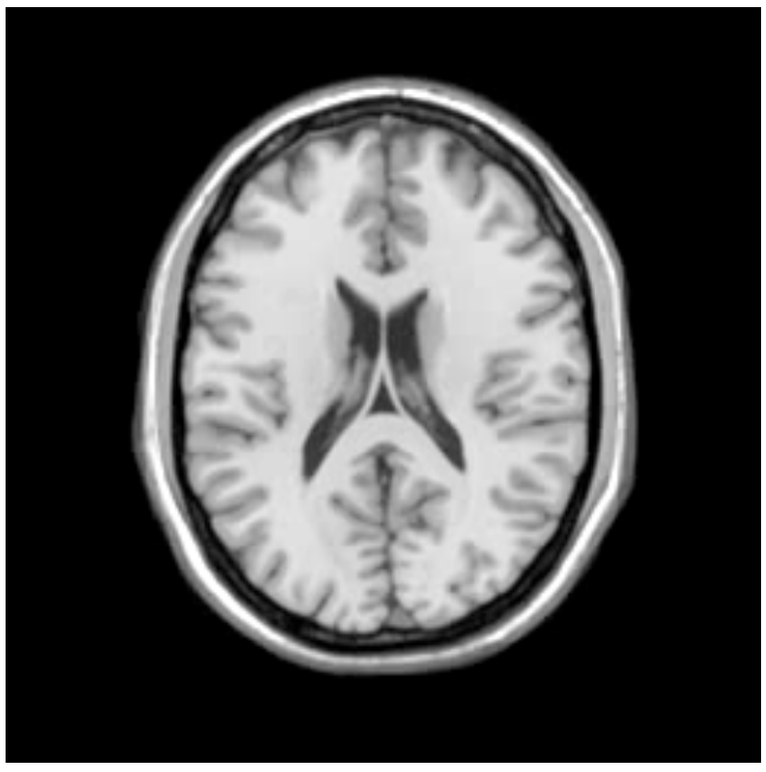
- Resampling: example



using nearest-neighbor interpolation



using linear interpolation



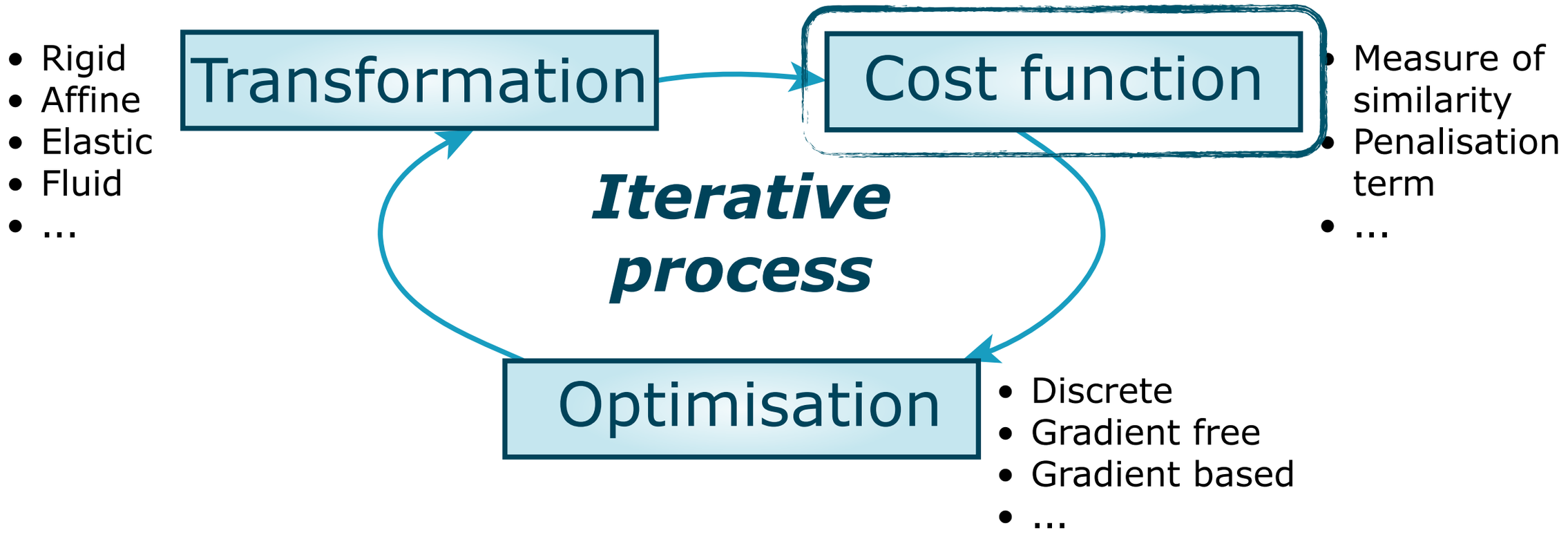
using cubic interpolation

Transformation

- Resampling
  - Registration can be a computationally expensive process
  - Need to find a balance between accuracy and computation time
    - Linear interpolation is often used (*only once - avoid multiple resampling*)

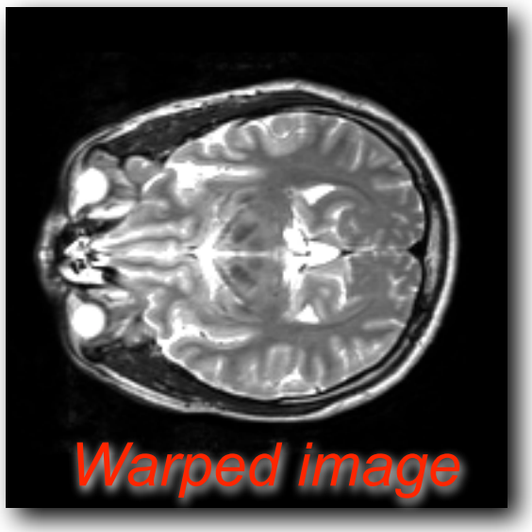
Medical image registration

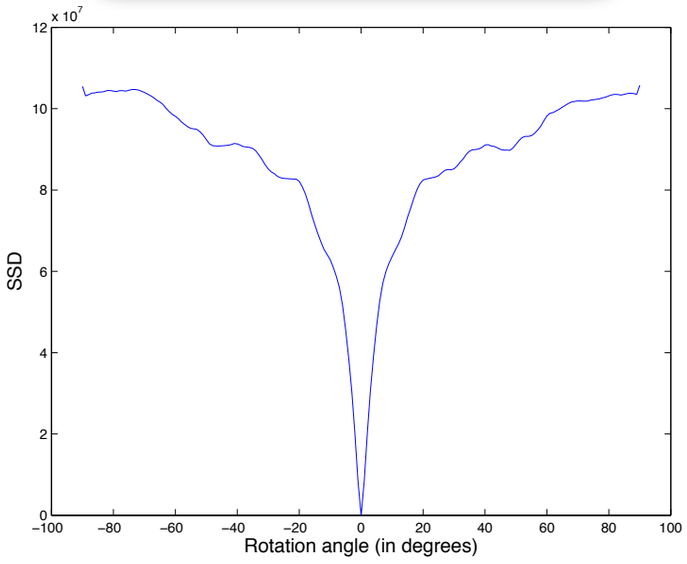
- Overall scheme

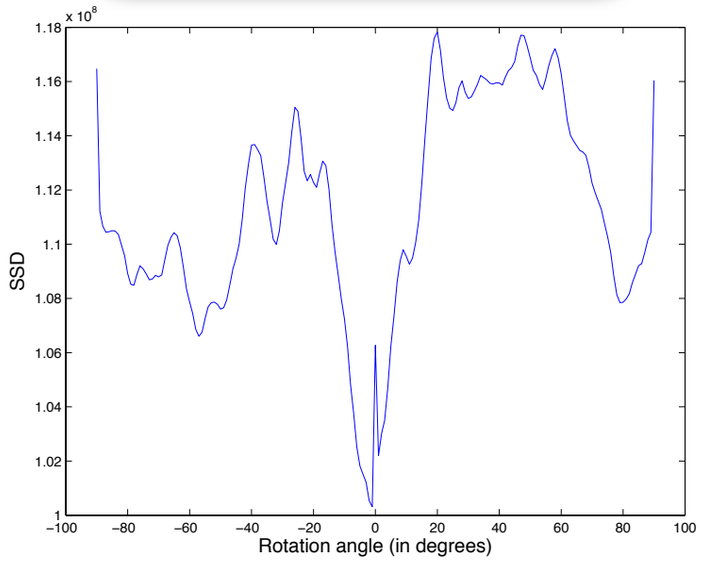


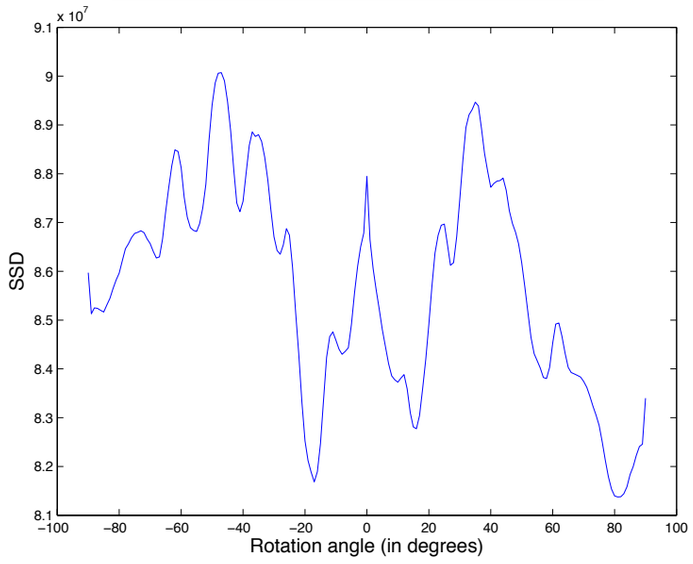
Transformation

- Measure of similarity - Example
  - Sum Squared Difference



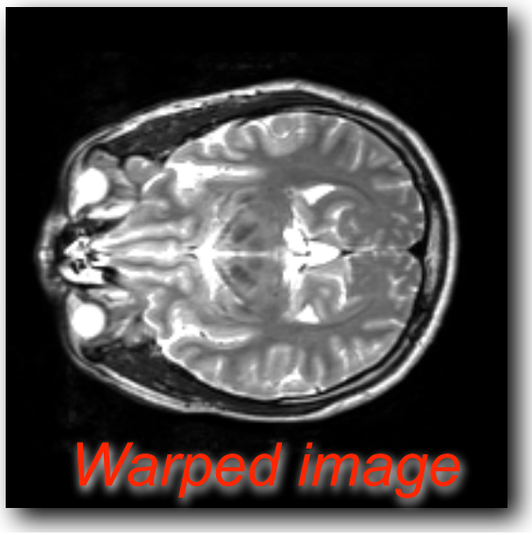


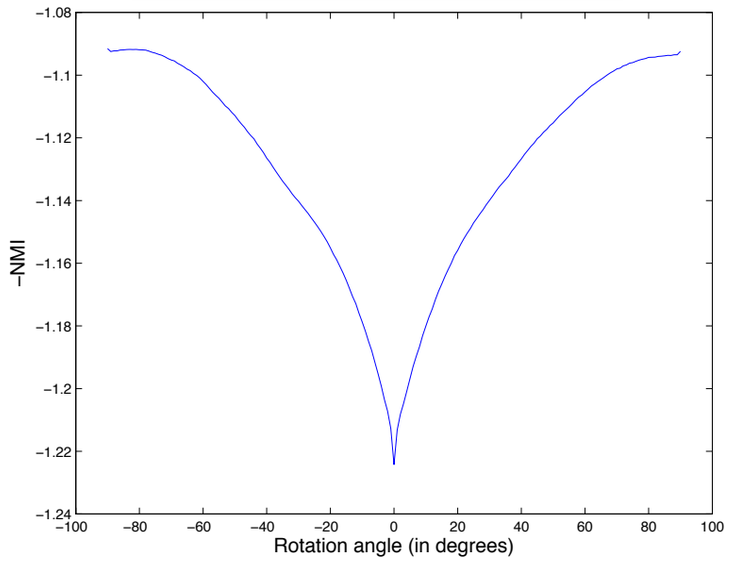


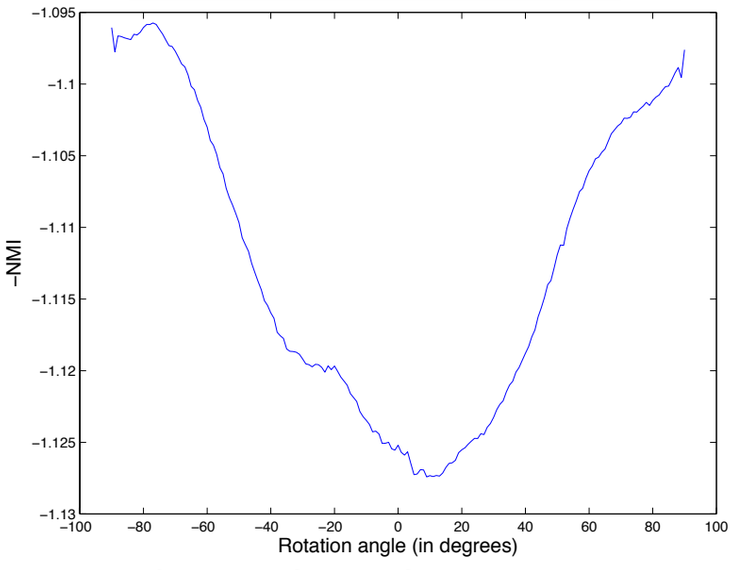


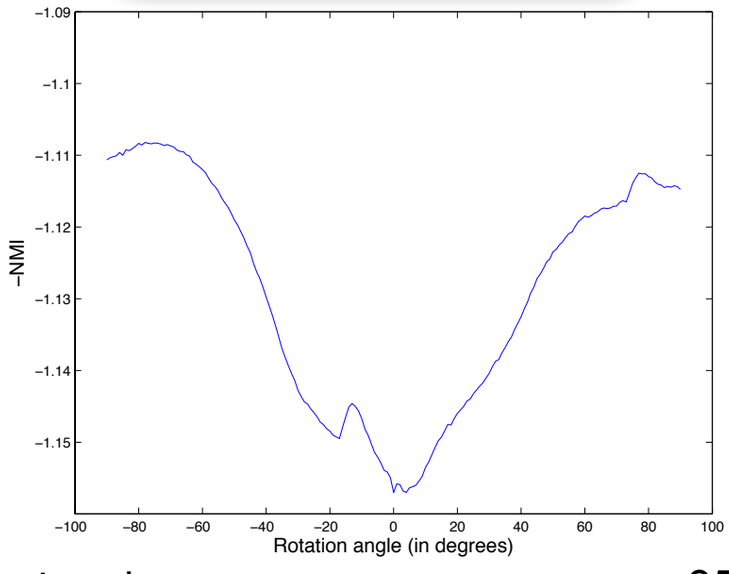
Transformation

- Measure of similarity - Example
  - Normalised Mutual Information







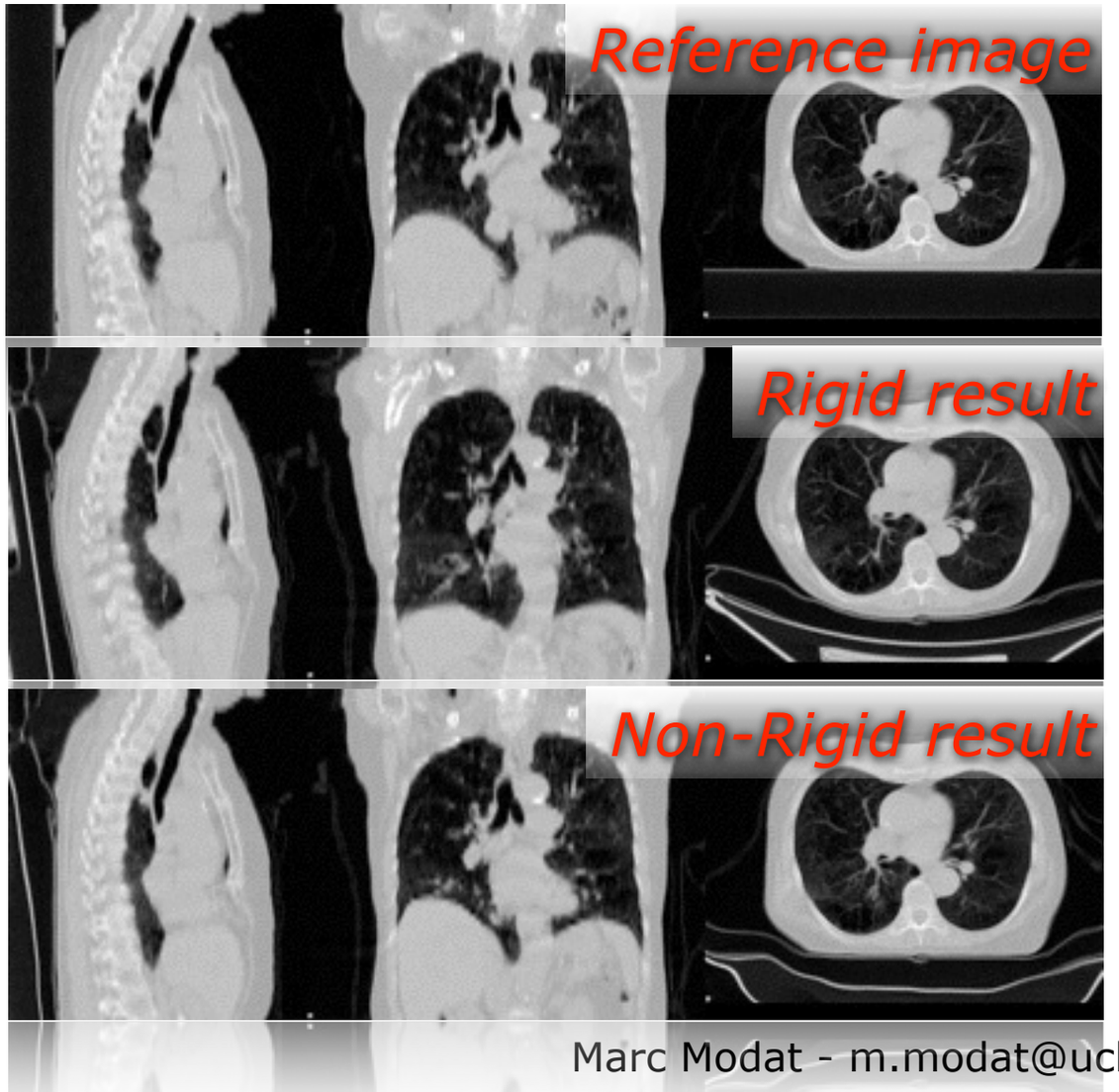


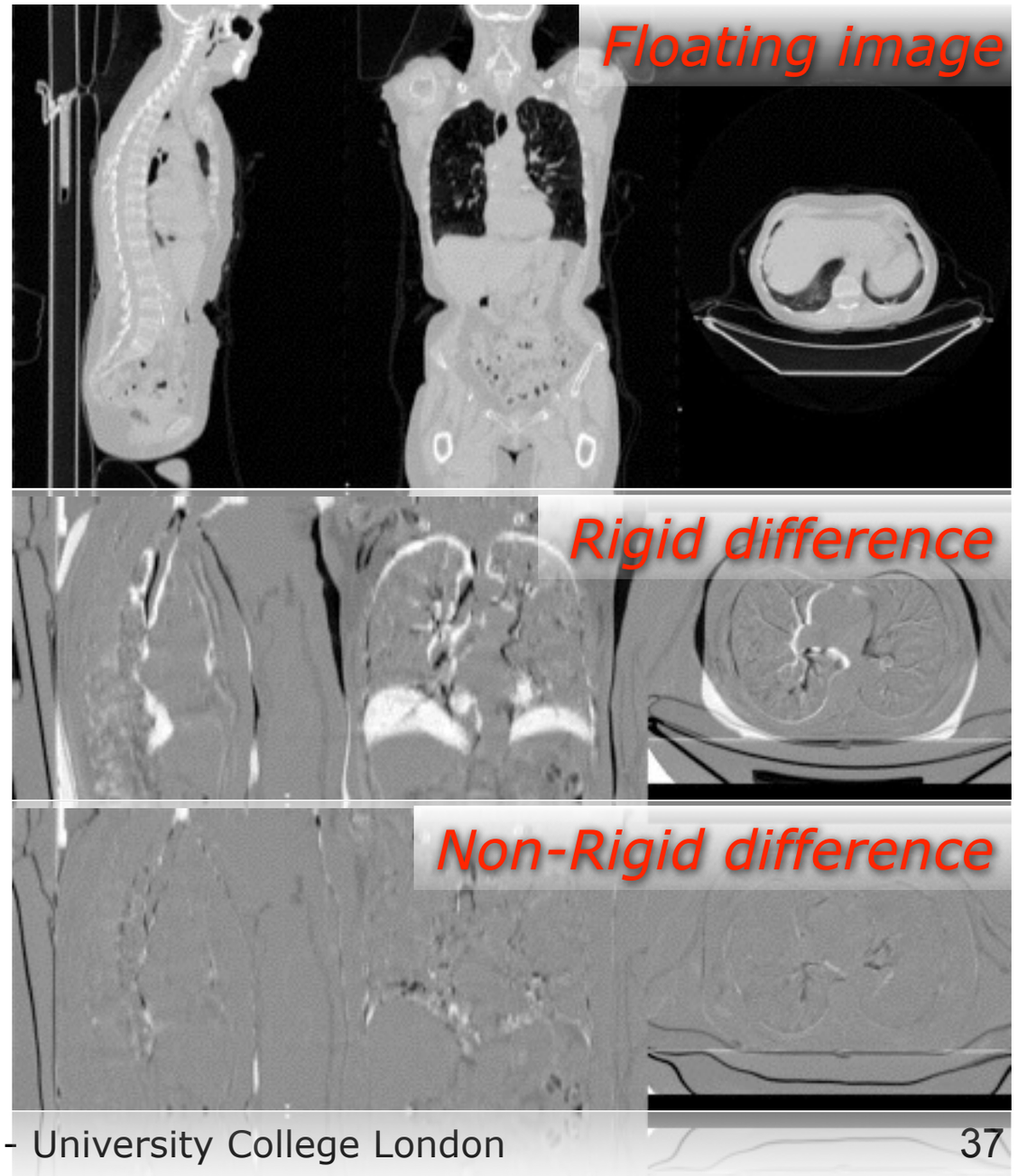
Registration - Examples of application

- Different types of registration
  - mono-modal
  - multi-modal
  - inter-patient
  - intra-patient

Registration - Examples of application

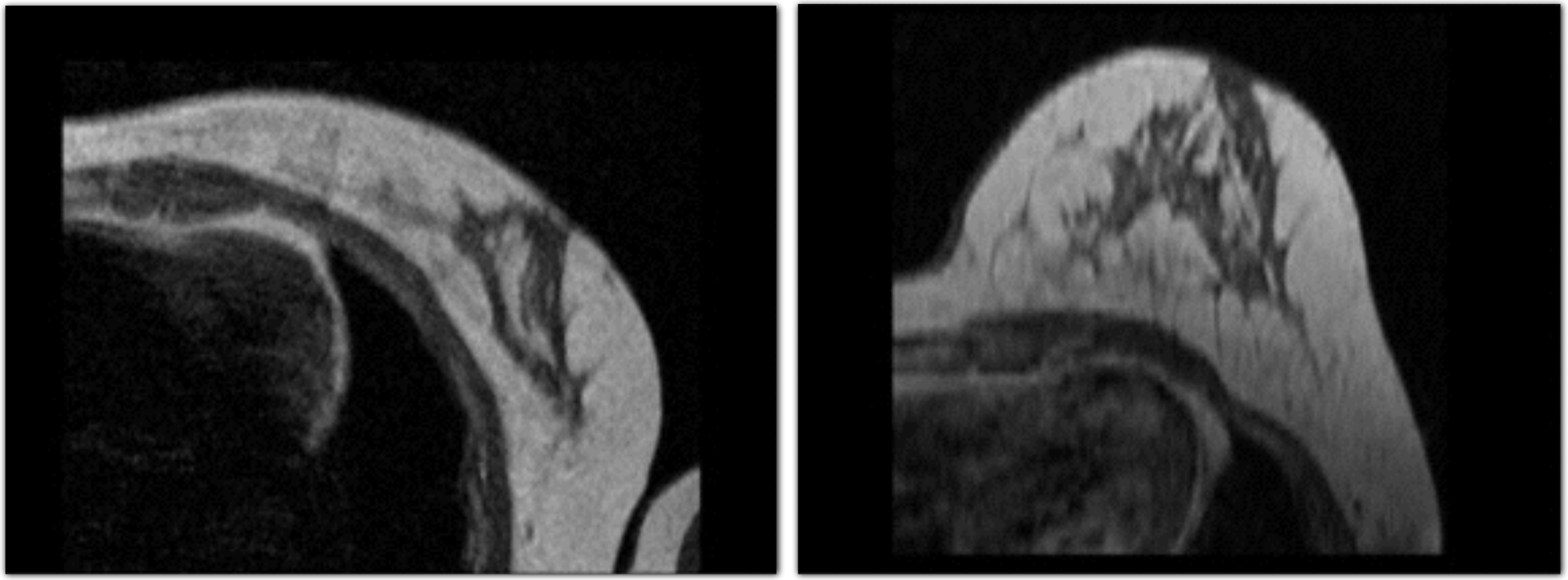
- Mono-modal intra-patient registration example
  - Ventilation motion





Registration - Examples of application

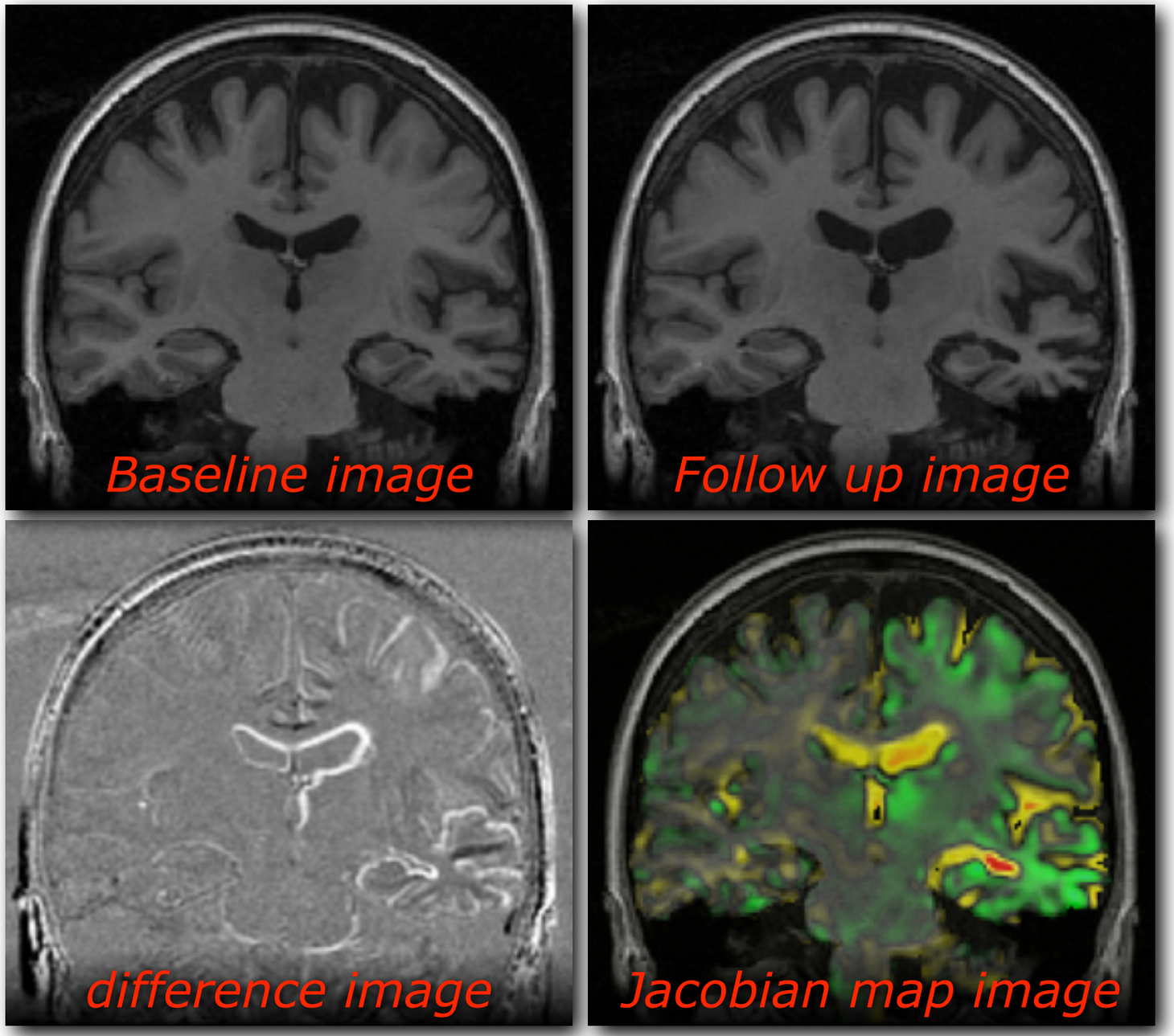
- Mono-modal intra-patient registration example
  - Prone / supine acquisition of breast MR images



Images from Carter *et al.*, MICCAI 2008

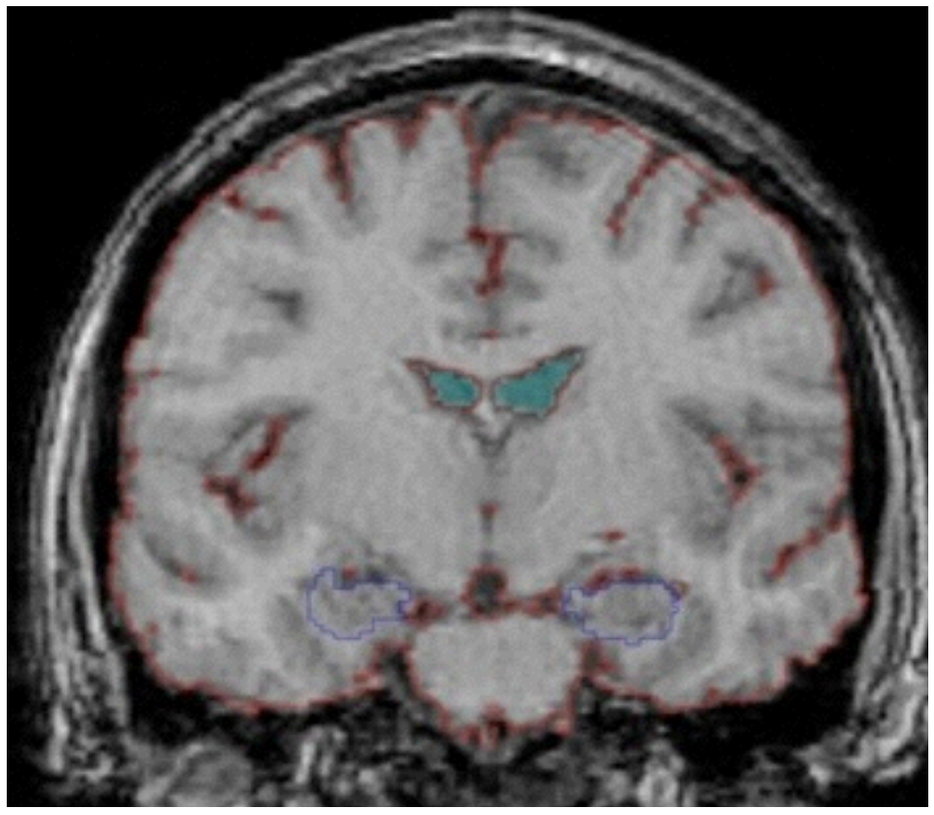
Registration - Examples of application

- Mono-modal intra-patient registration example
  - Tracking longitudinal changes

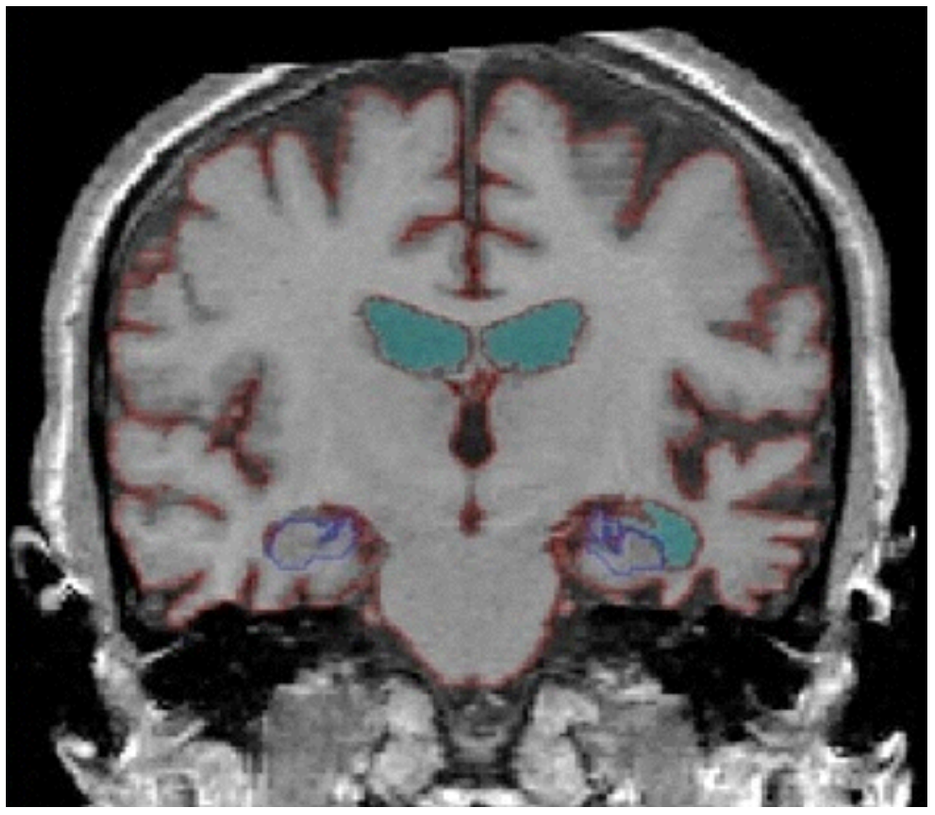


Registration - Examples of application

- Segmentation propagation
  - Concept: Register already segmented images to an unseen image and propagate the segmentation



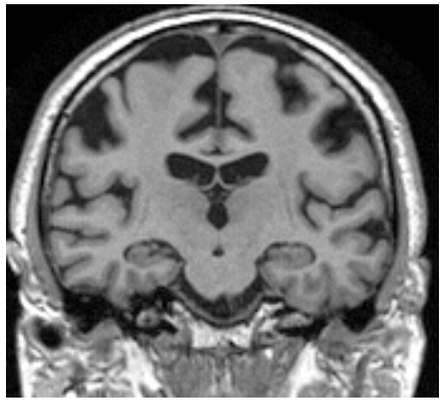
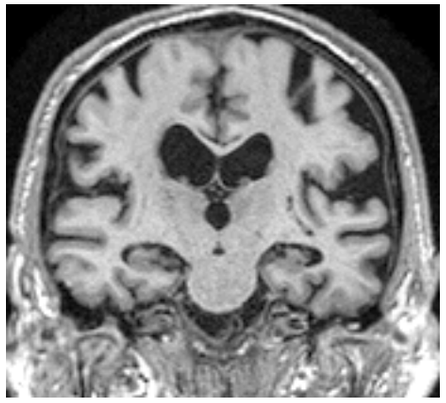
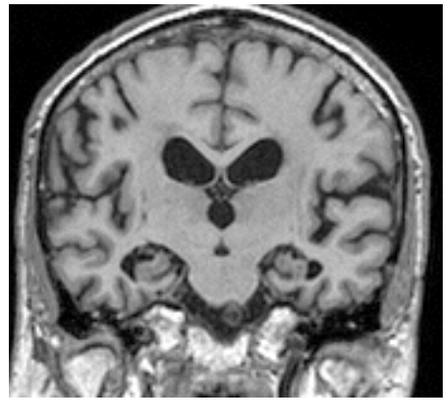
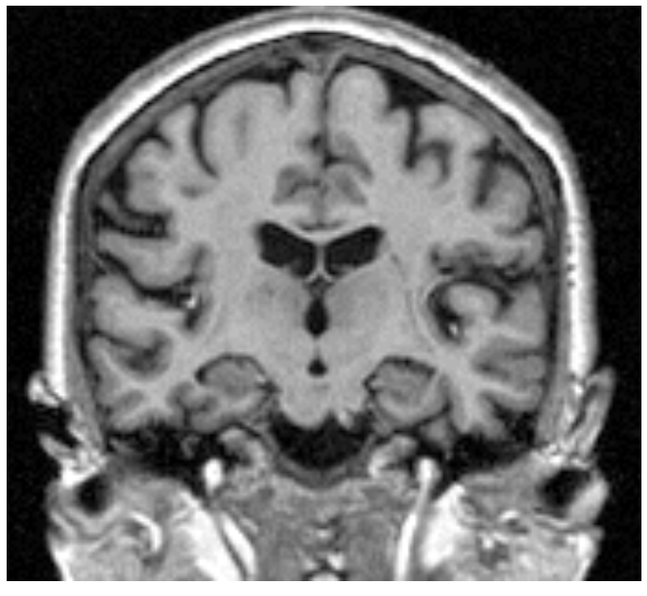
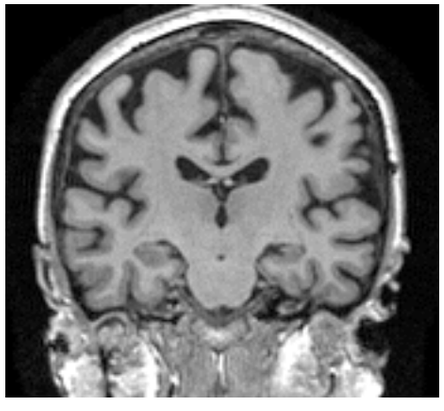
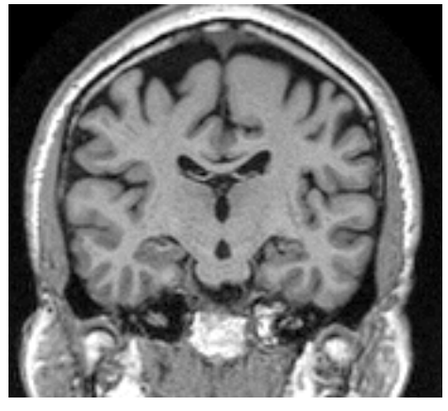
Manual segmentations
Healthy subject scan



Manual segmentations
AD patient scan

Registration - Examples of application

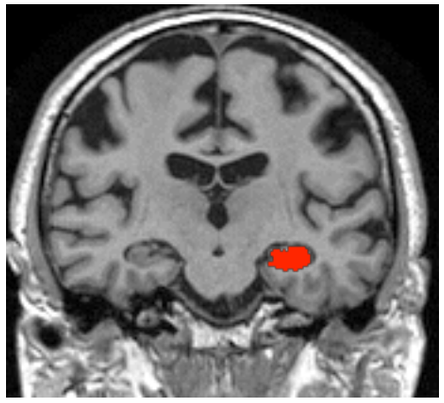
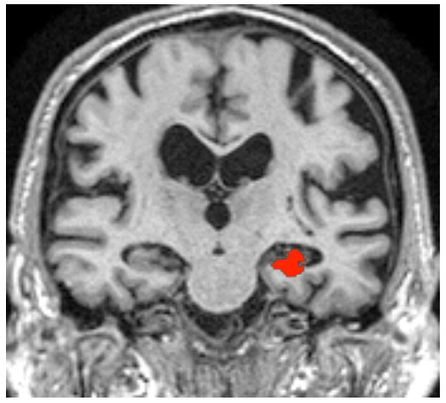
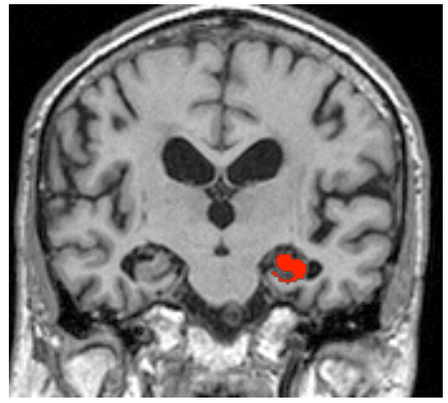
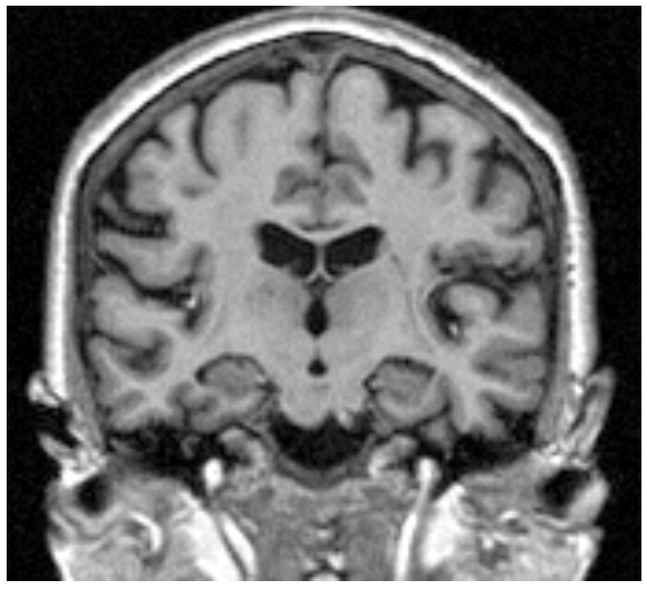
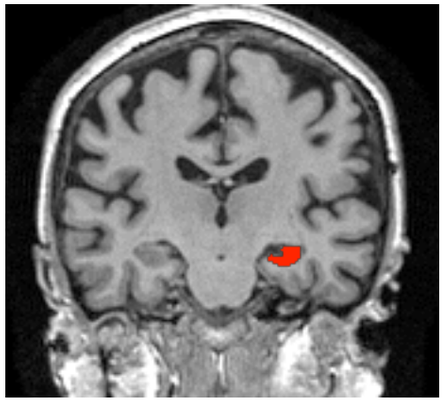
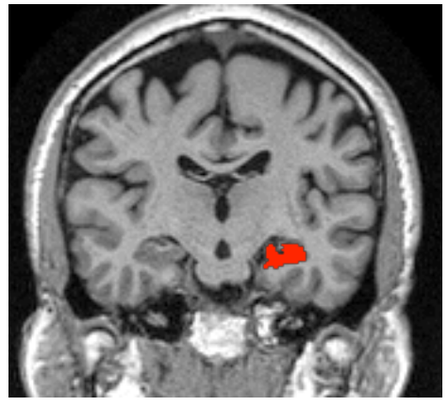
- Segmentation propagation
  - Example - Hippocampus segmentation

Unseen image

Registration - Examples of application

- Segmentation propagation
  - Example - Hippocampus segmentation

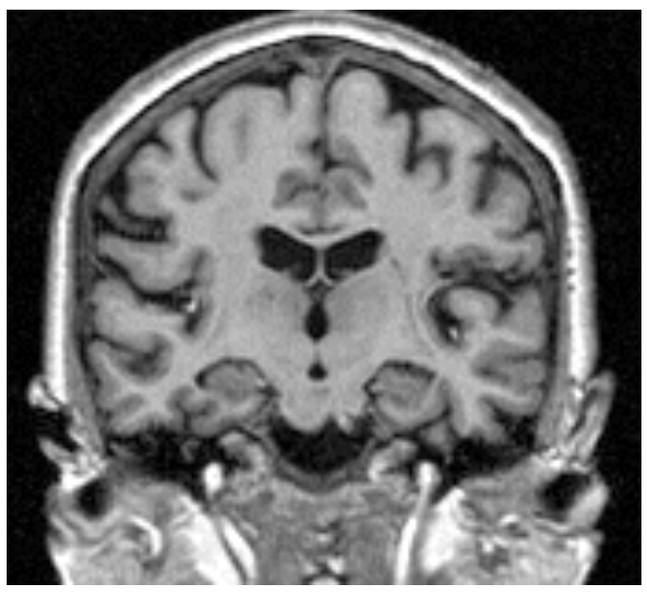
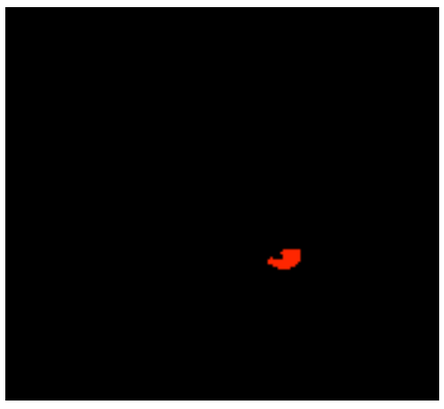







Unseen image

Registration - Examples of application

- Segmentation propagation
  - Example - Hippocampus segmentation

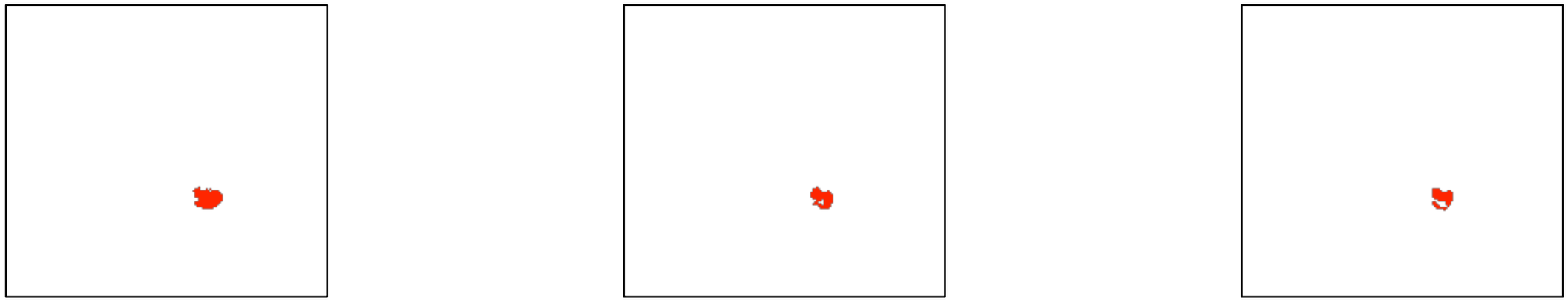


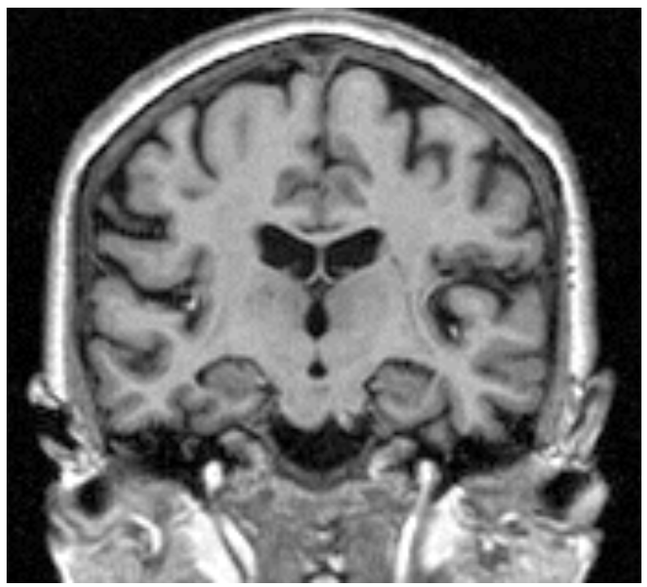




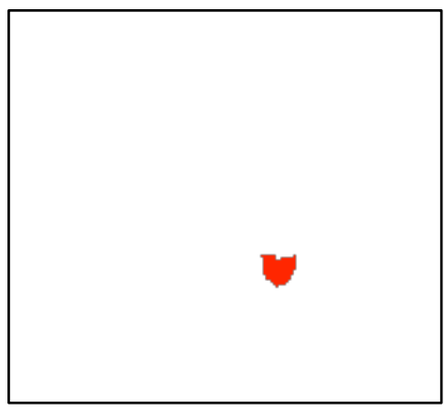

Unseen image

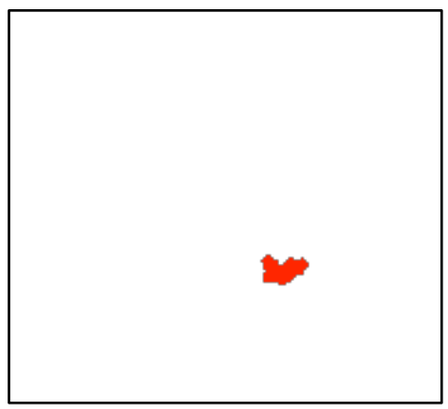
Registration - Examples of application

- Segmentation propagation
  - Example - Hippocampus segmentation





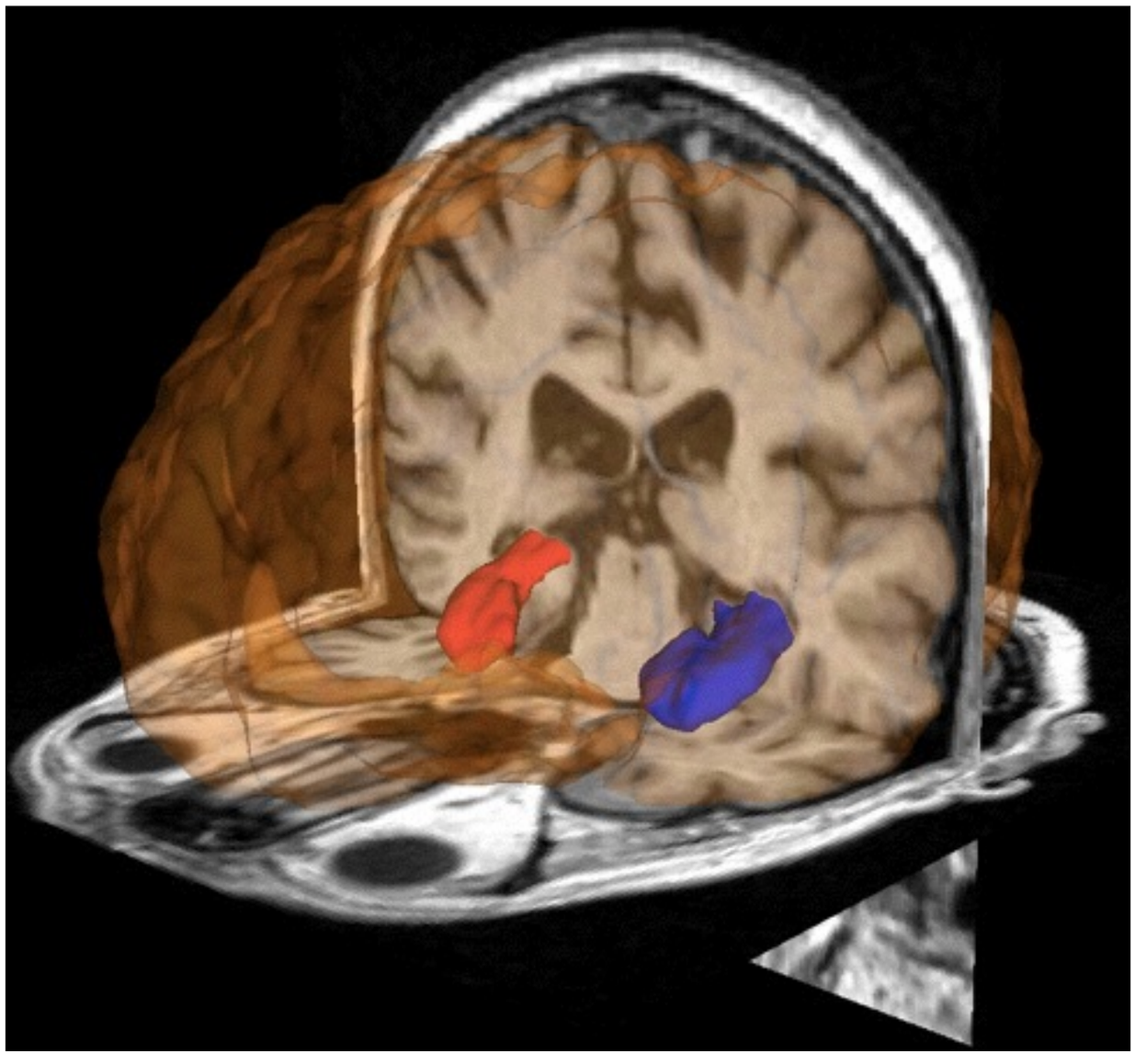


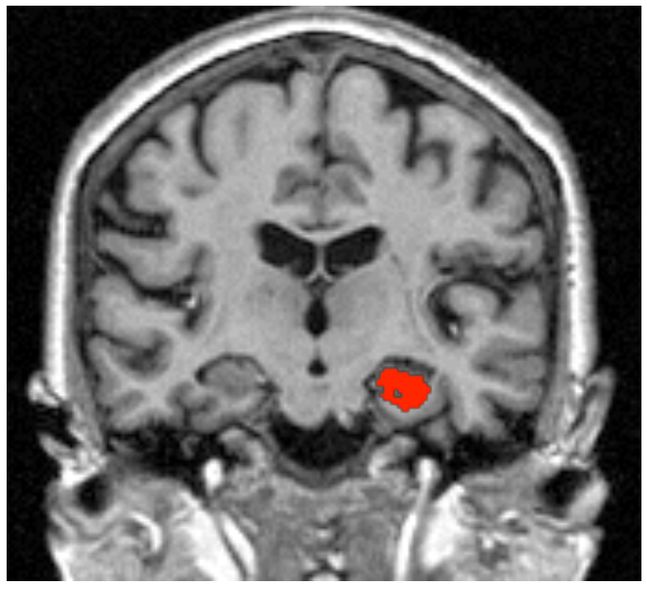


Unseen image

Registration - Examples of application

- Segmentation propagation
  - Example - Hippocampus segmentation

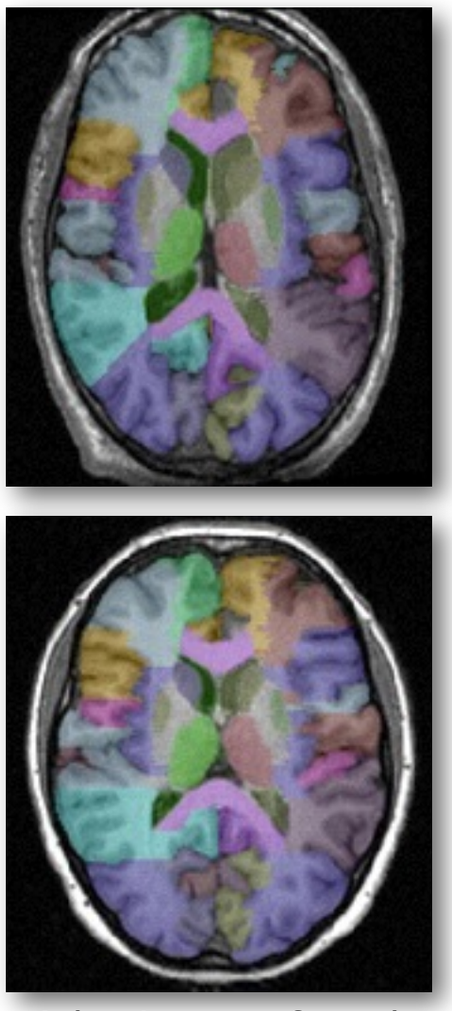


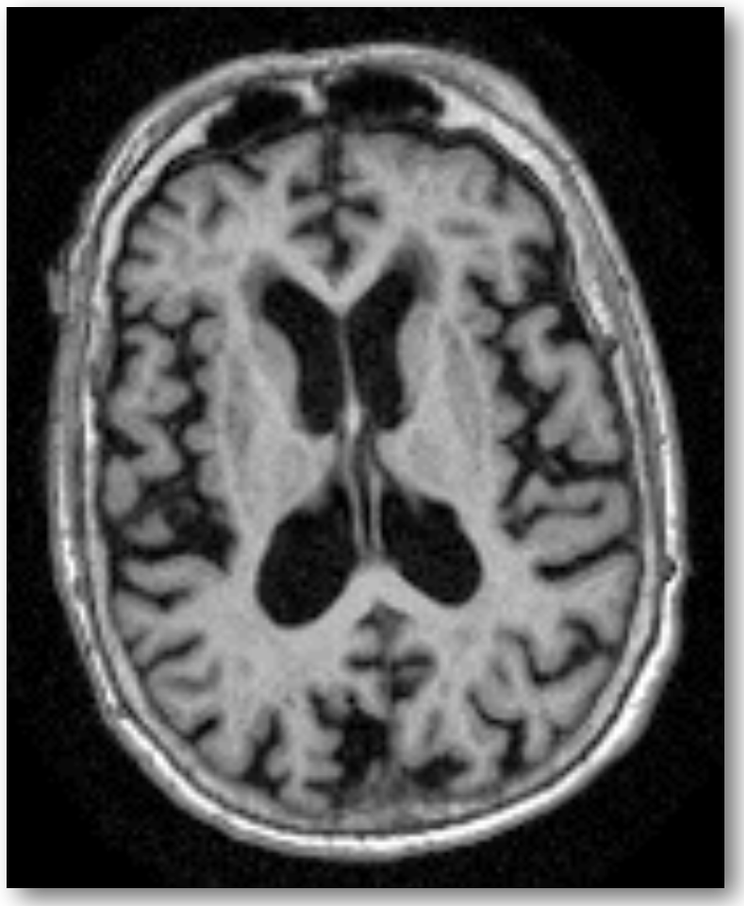


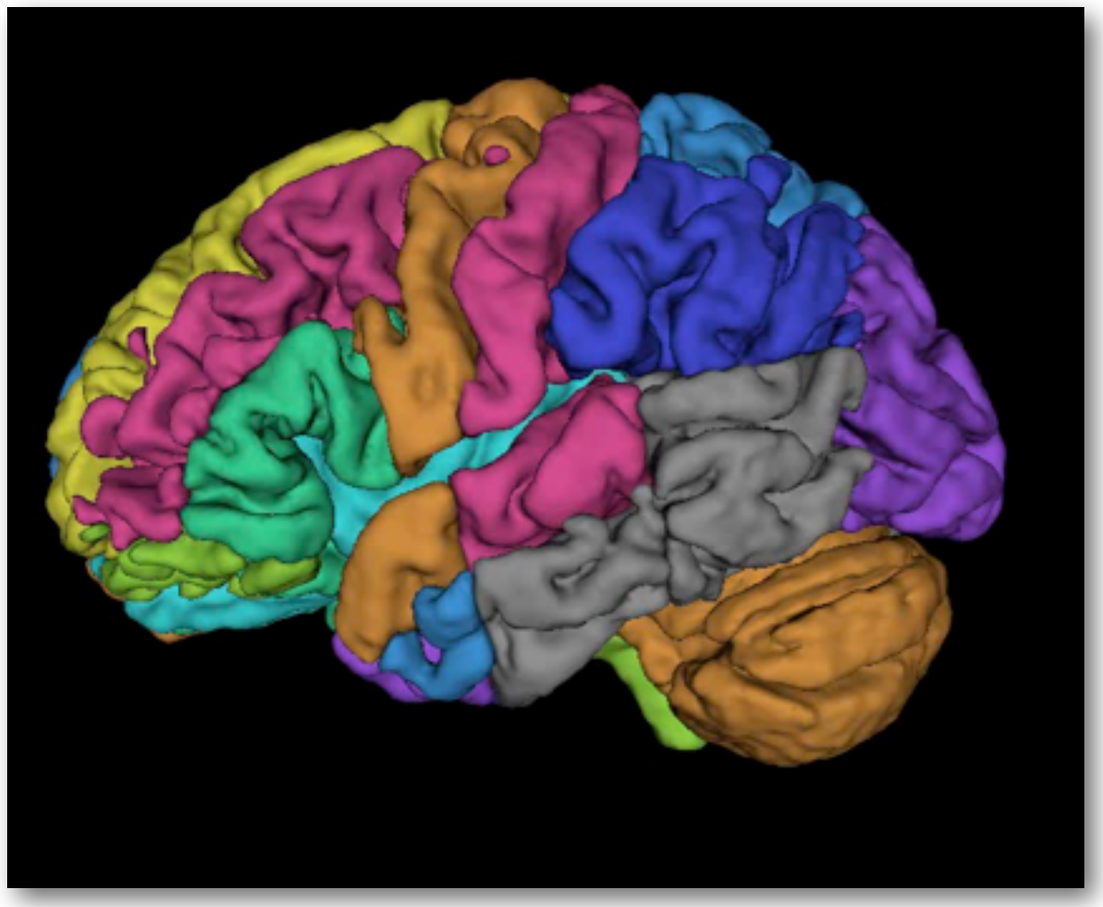
Unseen image

Registration - Examples of application

- Segmentation propagation
  - Example - Full brain parcelation







Atlas images from http://www.brain-development.org

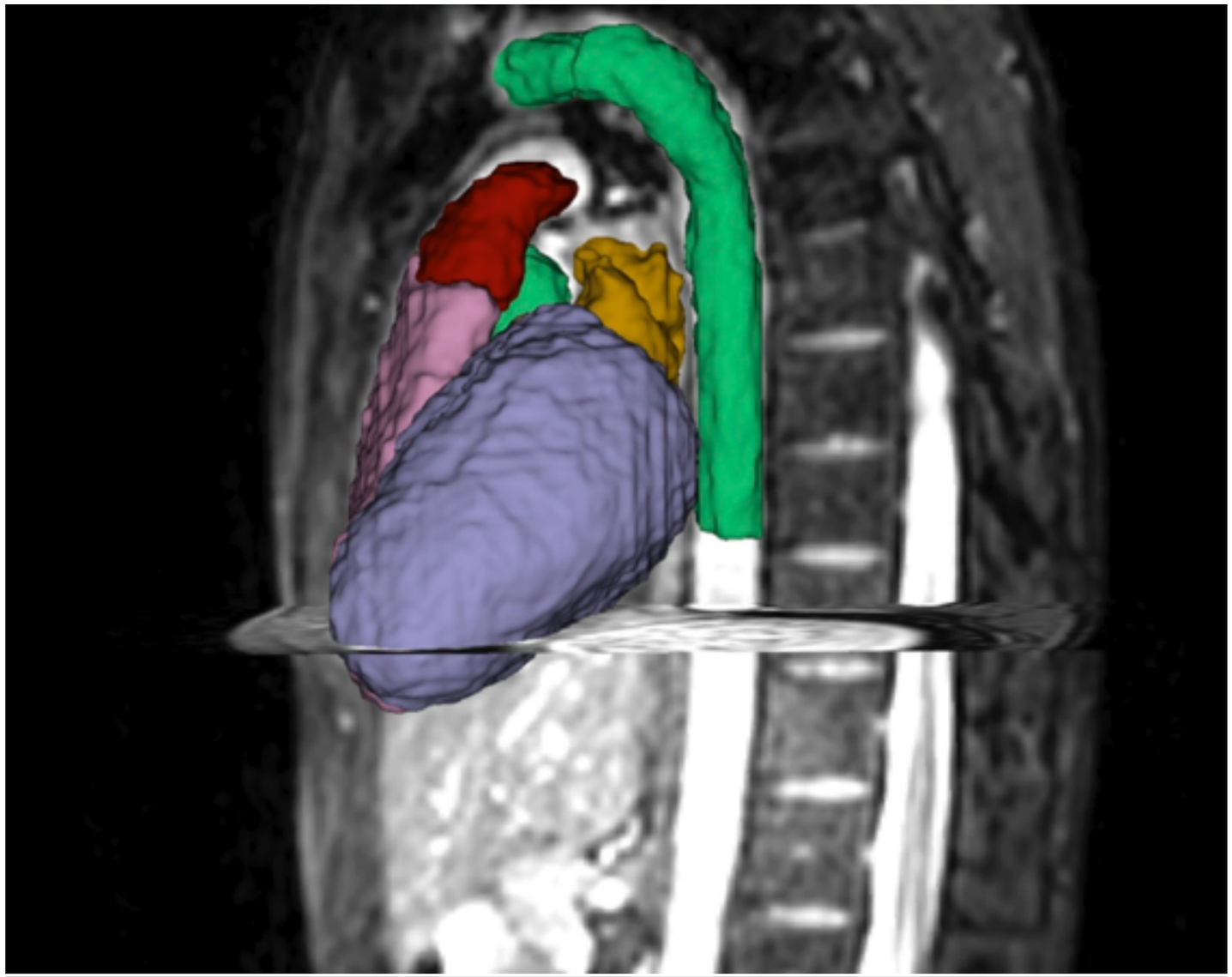
Registration - Examples of application

- Cardiac automated segmentation

Courtesy Maria Zuluaga

Registration - Examples of application

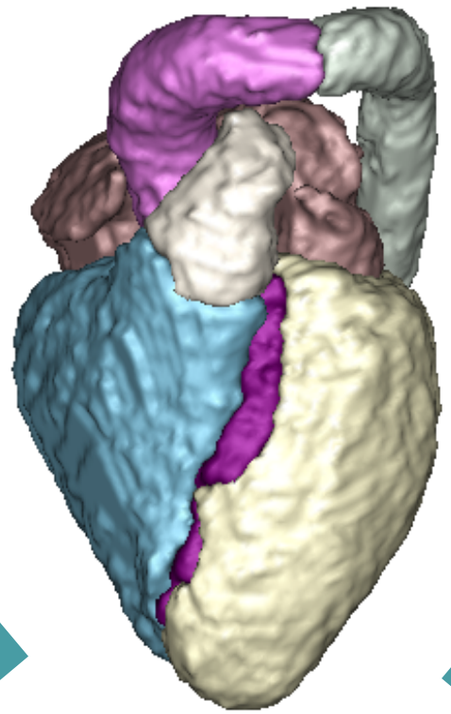
- Cardiac automated segmentation



Courtesy Maria Zuluaga

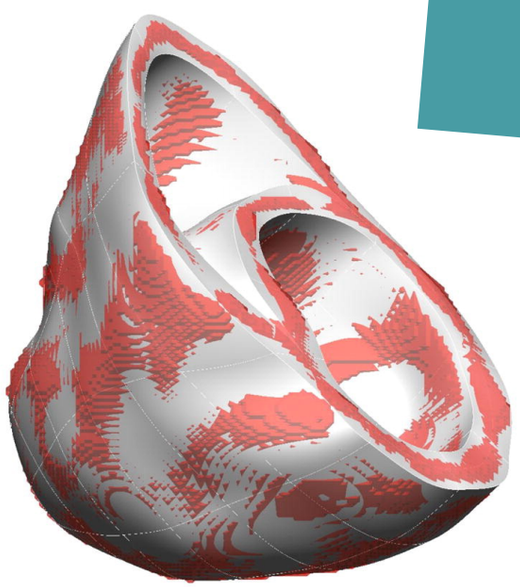
Registration - Examples of application

- Cardiac automated segmentation

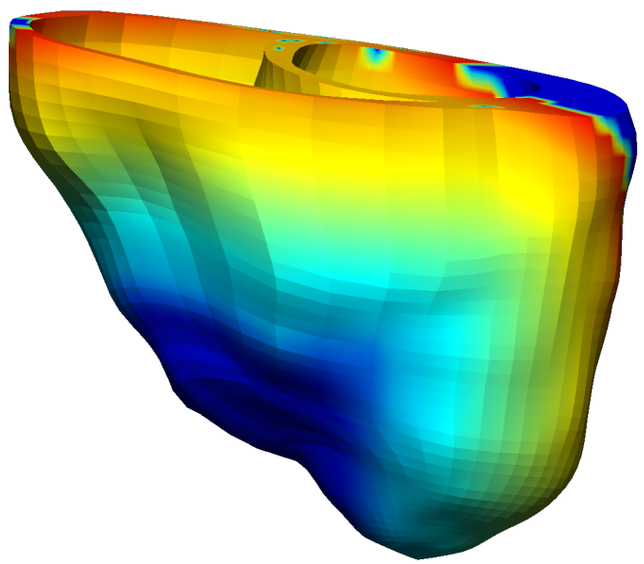


Whole heart segmentation

Personalised cubic Hermite shape

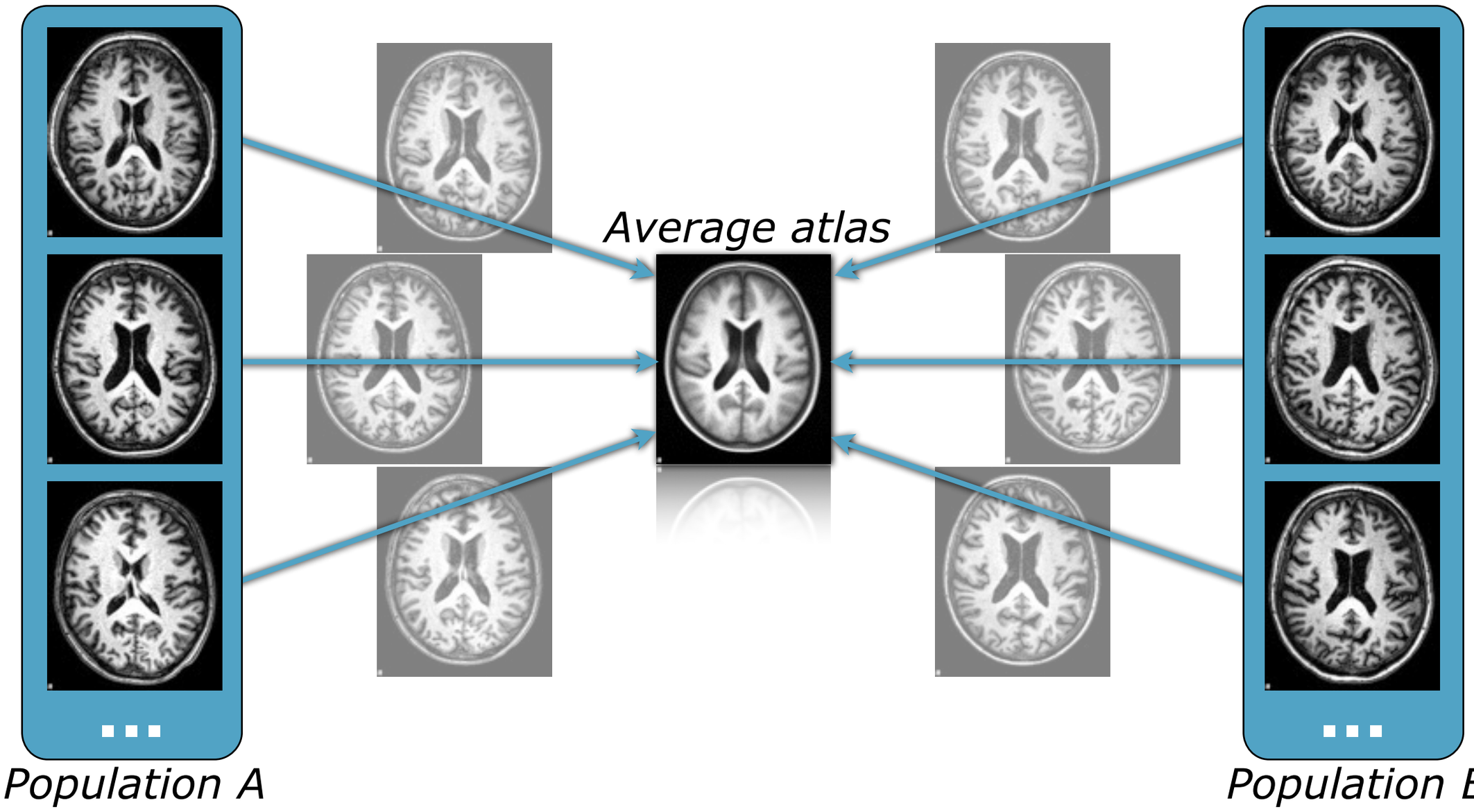


Activation time propagation plot



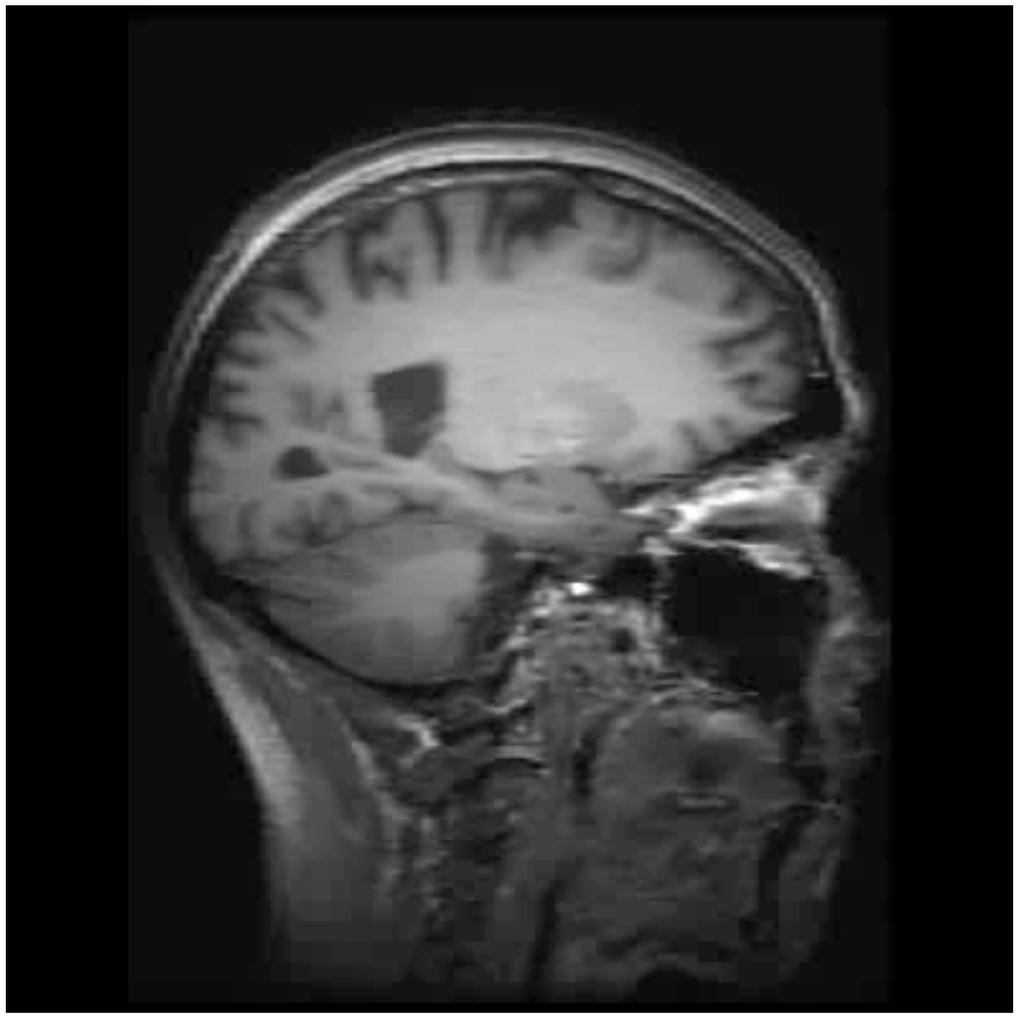
Registration - Examples of application

- Groupwise registration and morphometric studies
  - Voxel-based / Deformation based / Transformation based

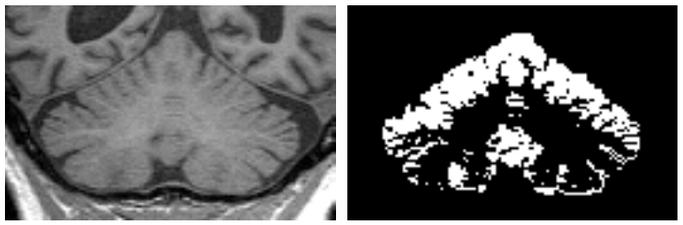


Registration - Examples of application

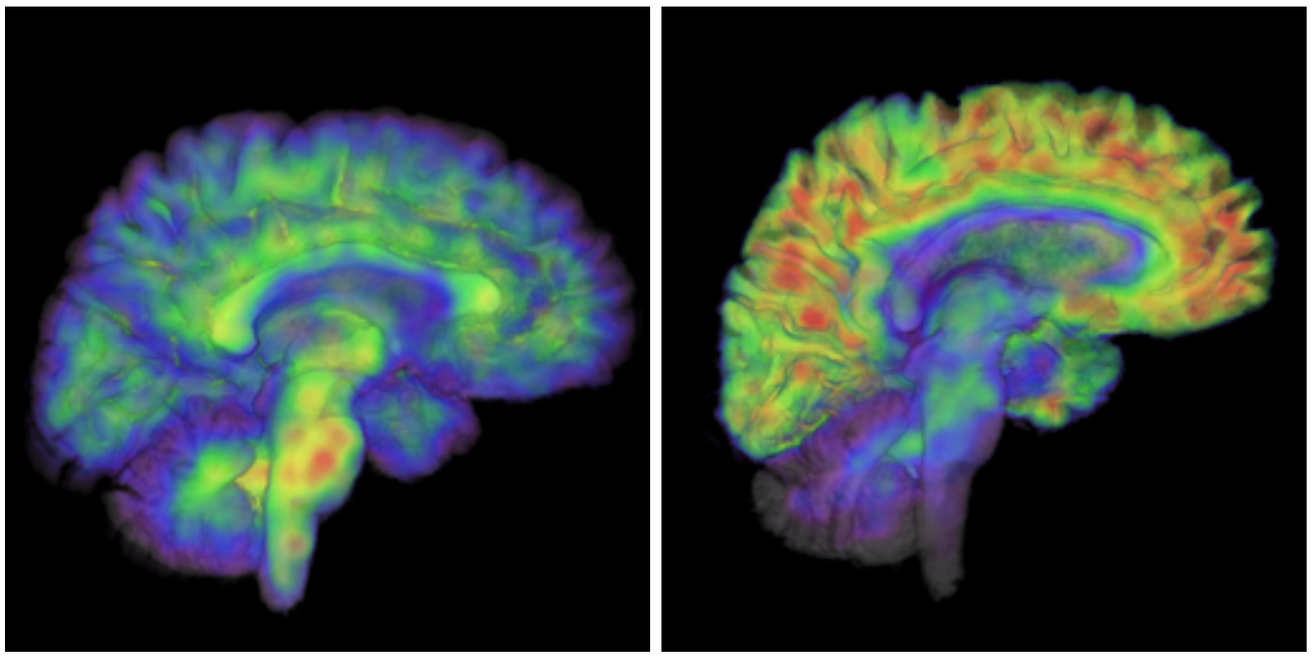
- Multi-modal intra-patient registration example



MRI / PET registration



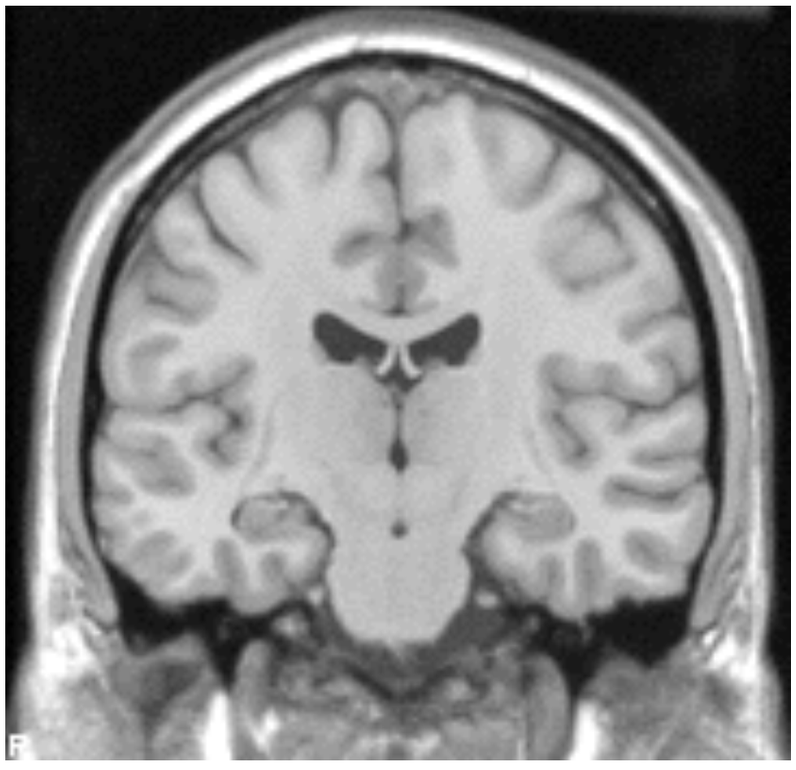
Grey matter segmentation



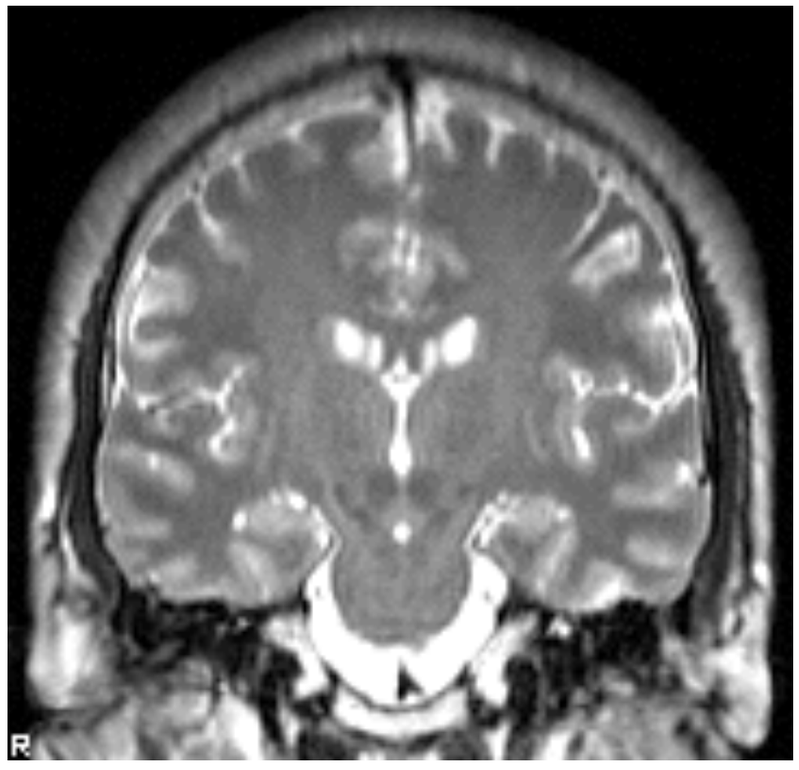
Normalised uptake values

Registration - Examples of application

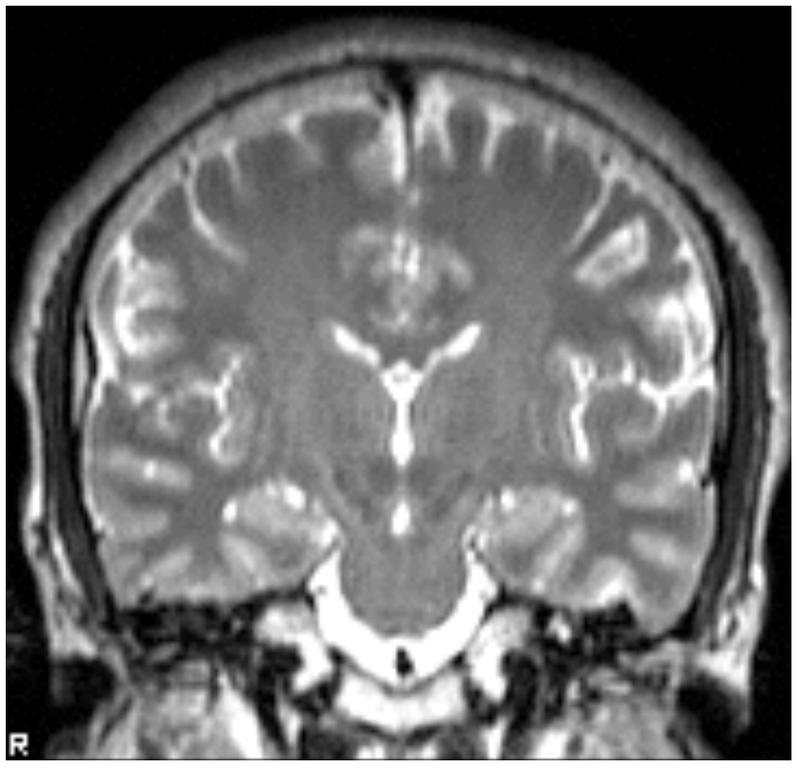
- Multi-modal inter-patient registration example



Reference image



MRI T1w/T2w example

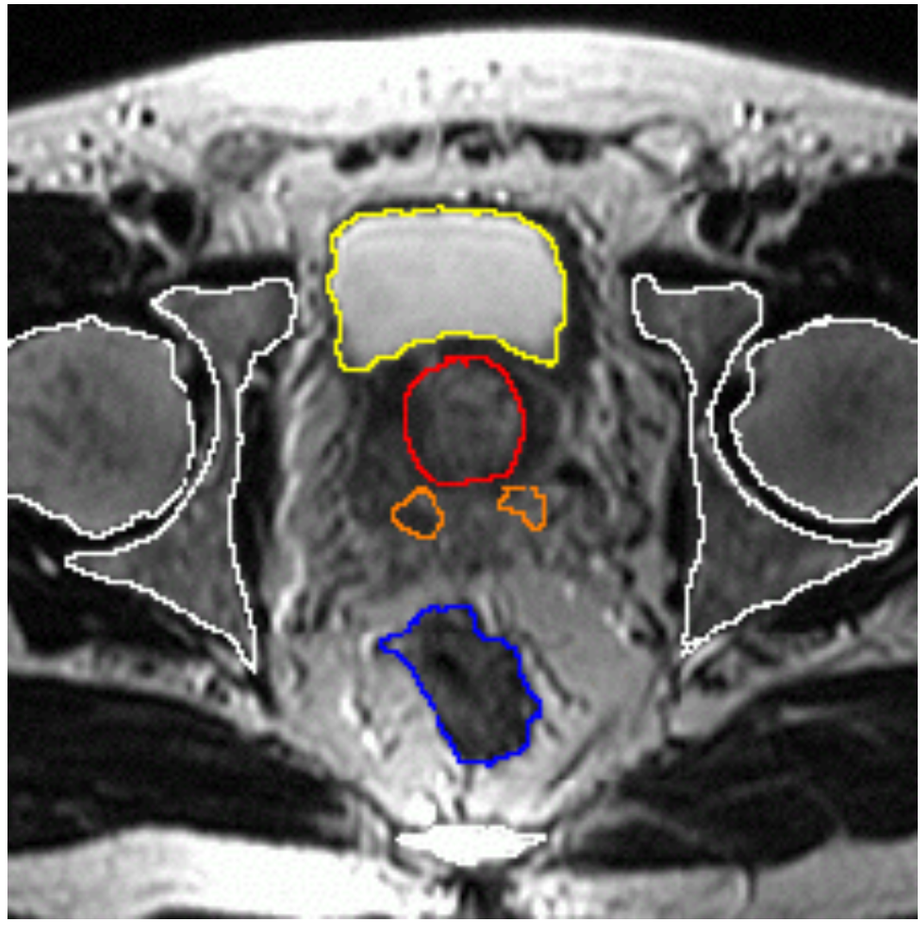


Floating image

Registration - Examples of application

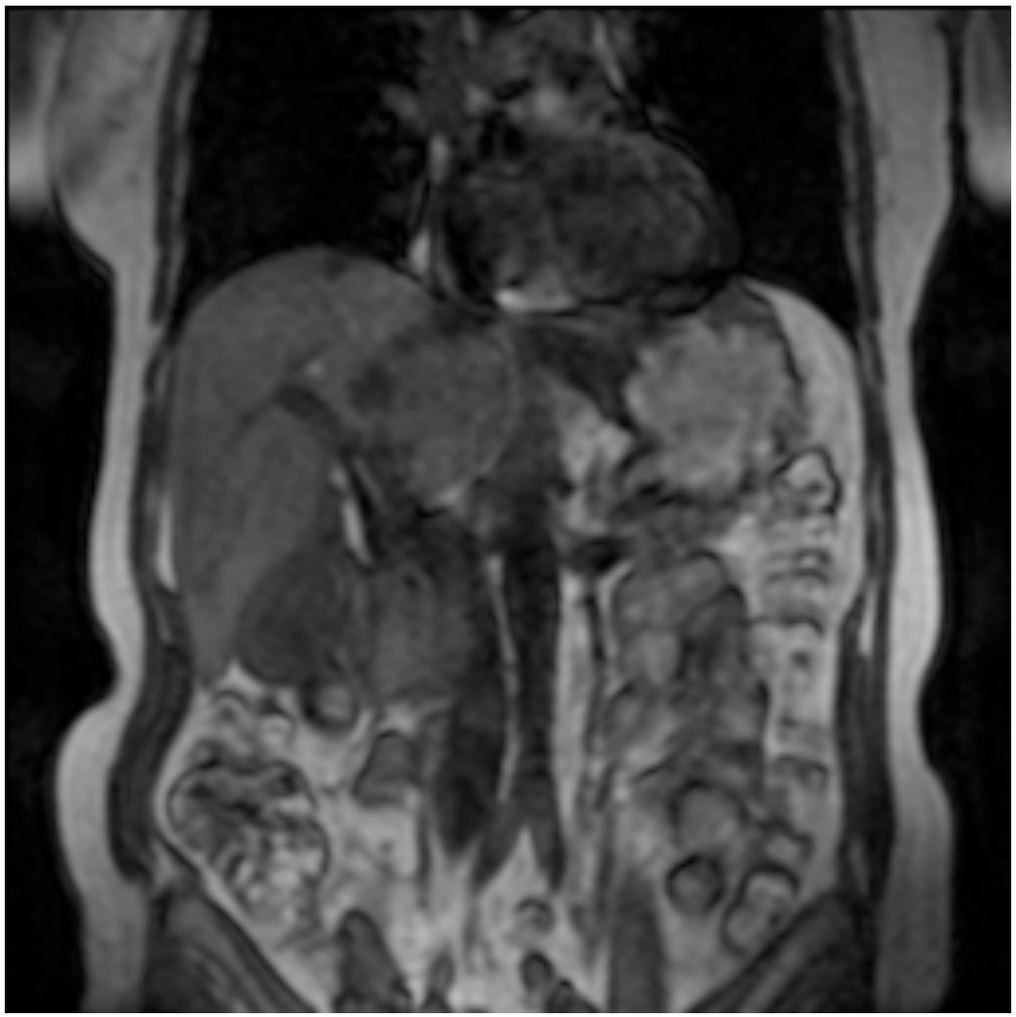
- Multi-modal intra-patient registration example

MR image / CT registration



Registration - Examples of application

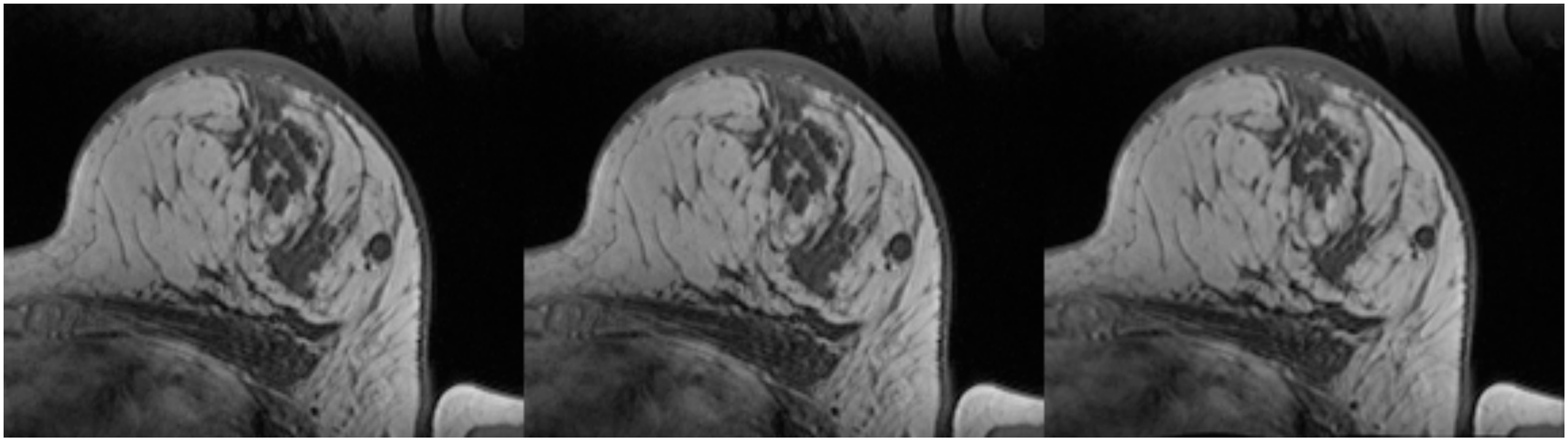
- Dynamic contrast enhancement



Courtesy Andrew Melbourne

Registration - Examples of application

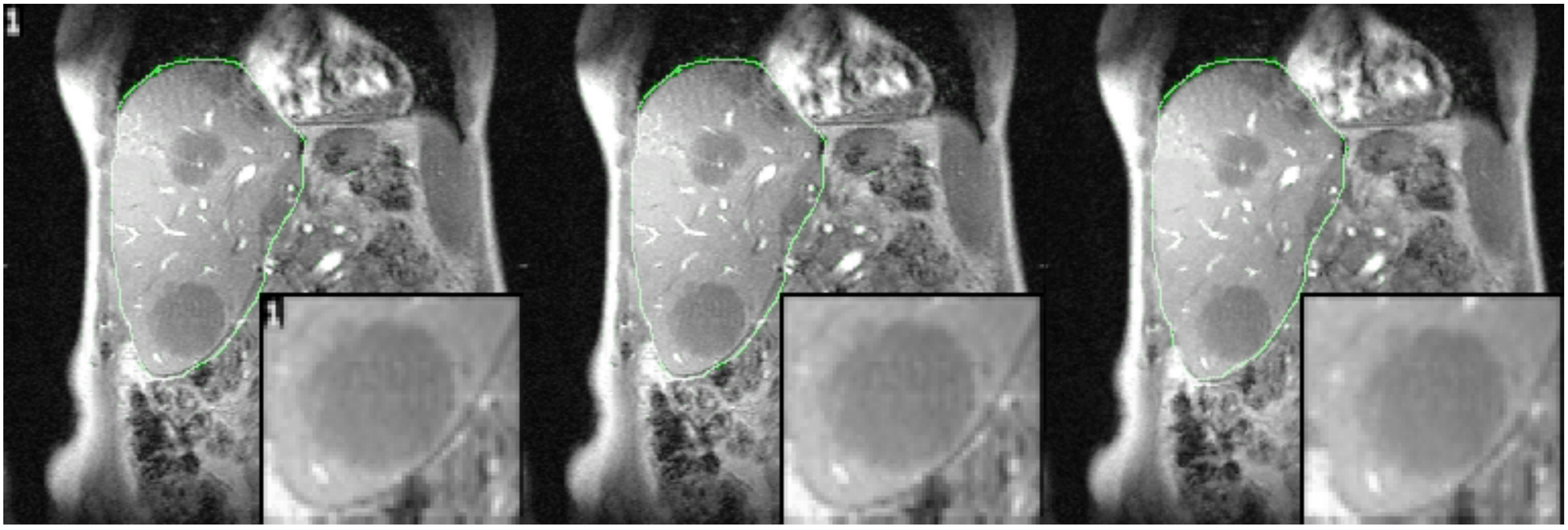
- Dynamic contrast enhancement



Courtesy Andrew Melbourne

Registration - Examples of application

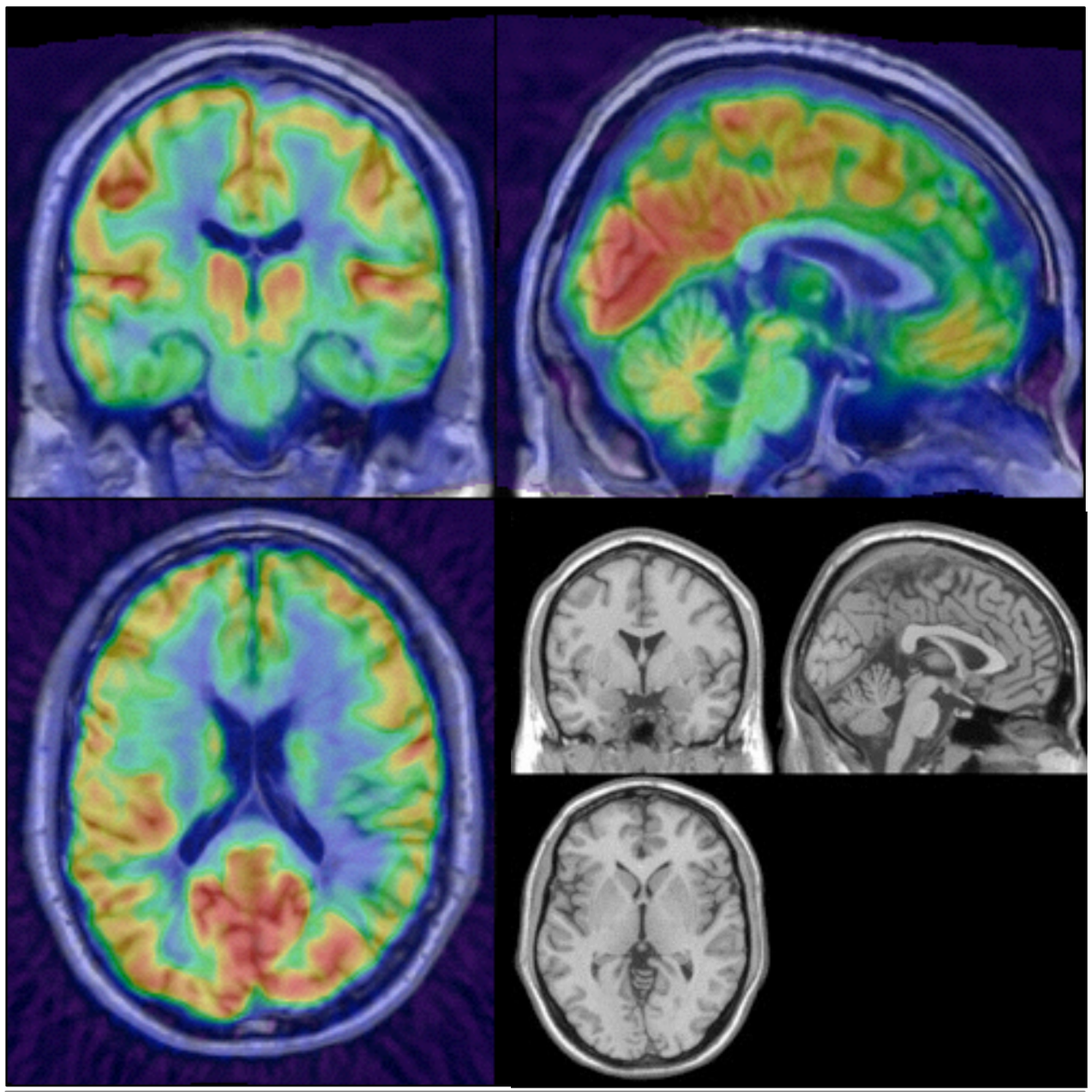
- Dynamic contrast enhancement



Courtesy Andrew Melbourne

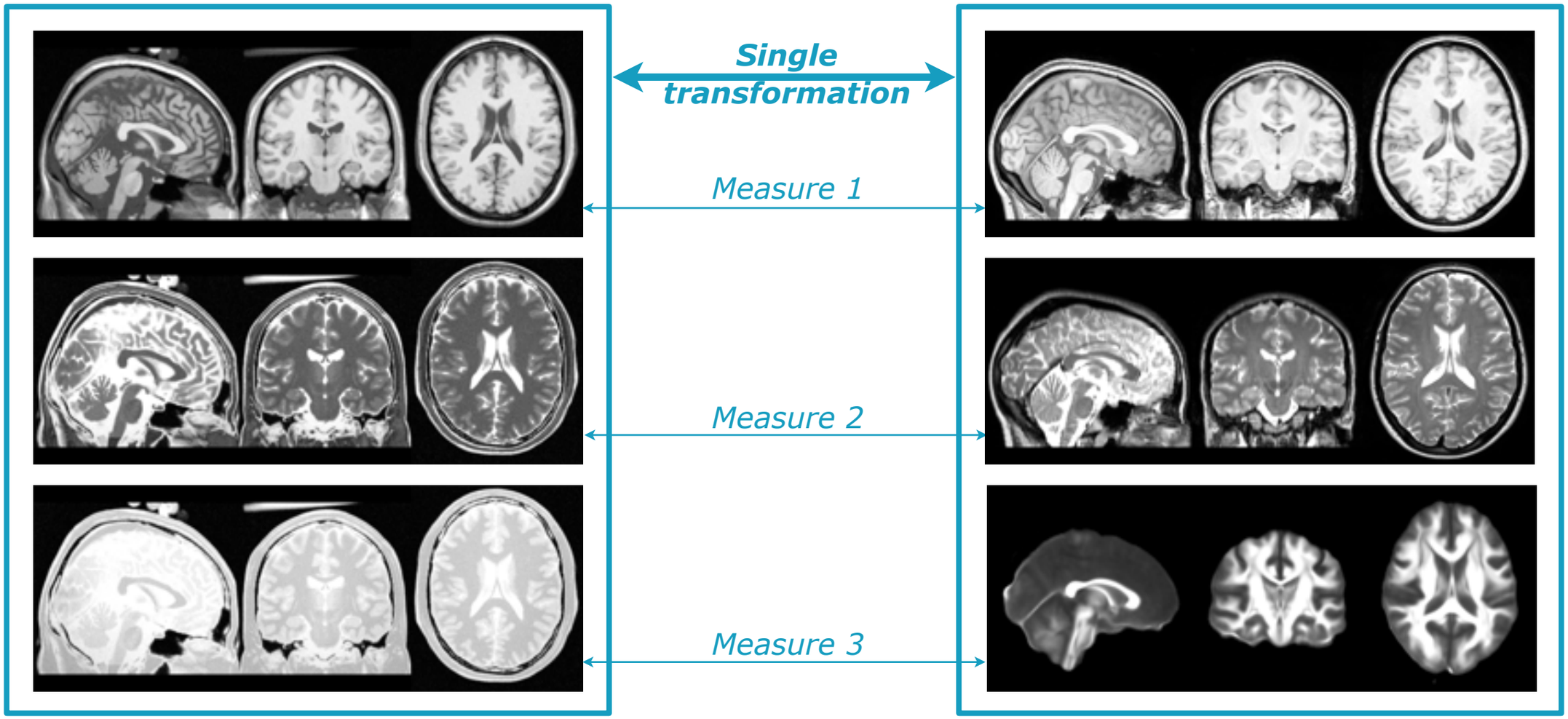
Registration - Examples of application

- "Combined" registration



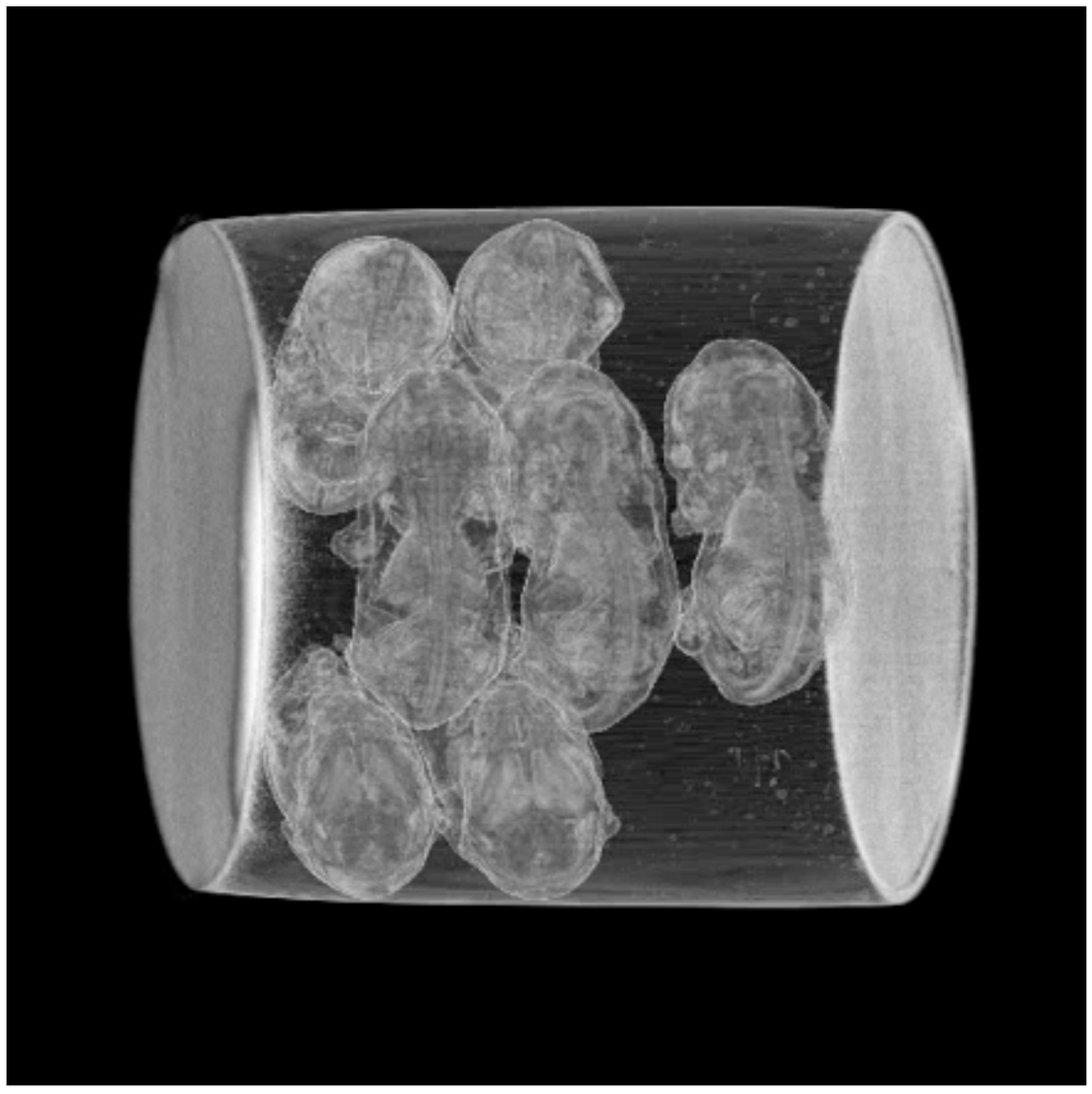
Registration - Examples of application

- Multi-volume and multi-modal registration
  - Possibility to combine information from multiple modalities using multiple measures of similarity into a common scheme



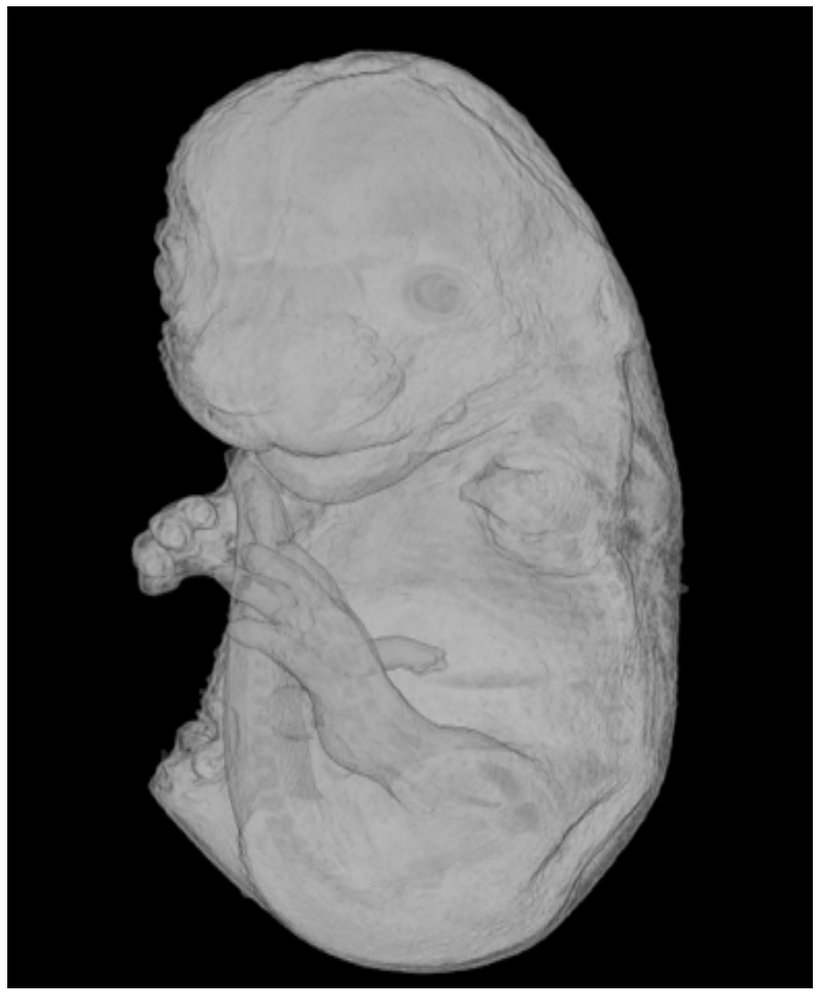
Registration - Examples of application

- Applied to small animal imaging
  - Example: mouse embryos



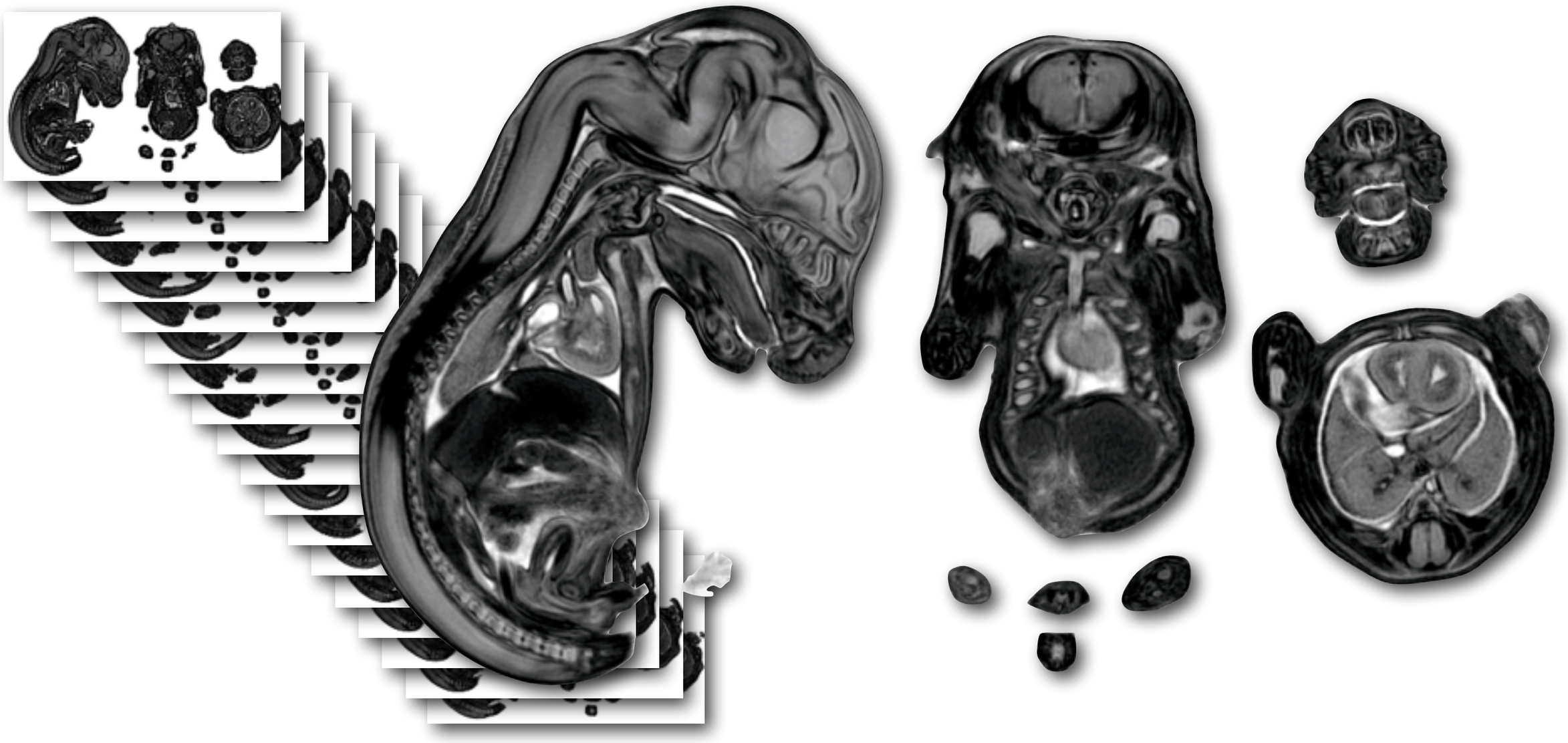
Registration - Examples of application

- Applied to small animal imaging
  - Example: mouse embryos



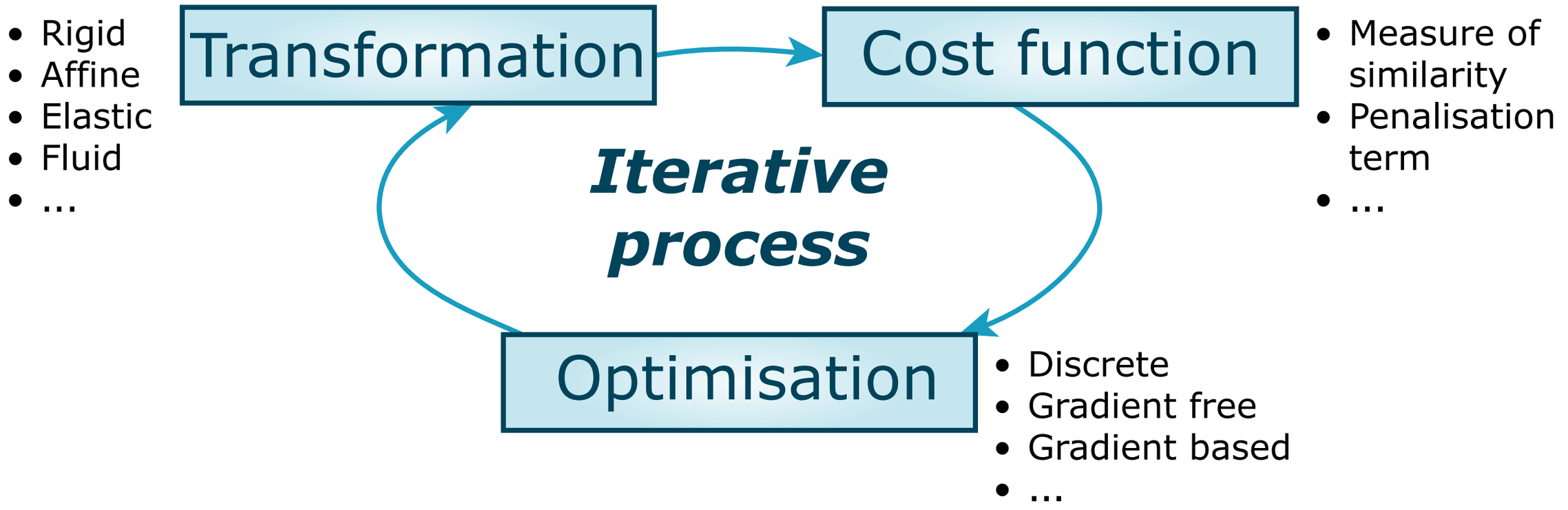
Registration - Examples of application

- Applied to small animal imaging
  - Example: mouse embryos



Medical image registration

- Overall scheme



Questions?