Image registration

Quantitative and Functional Imaging

BME 4420/7450

Fall 2022

Topics

- What is image registration?
- Why register images?
- Classes of registration techniques
- Measuring the quality of image registration
- Examples

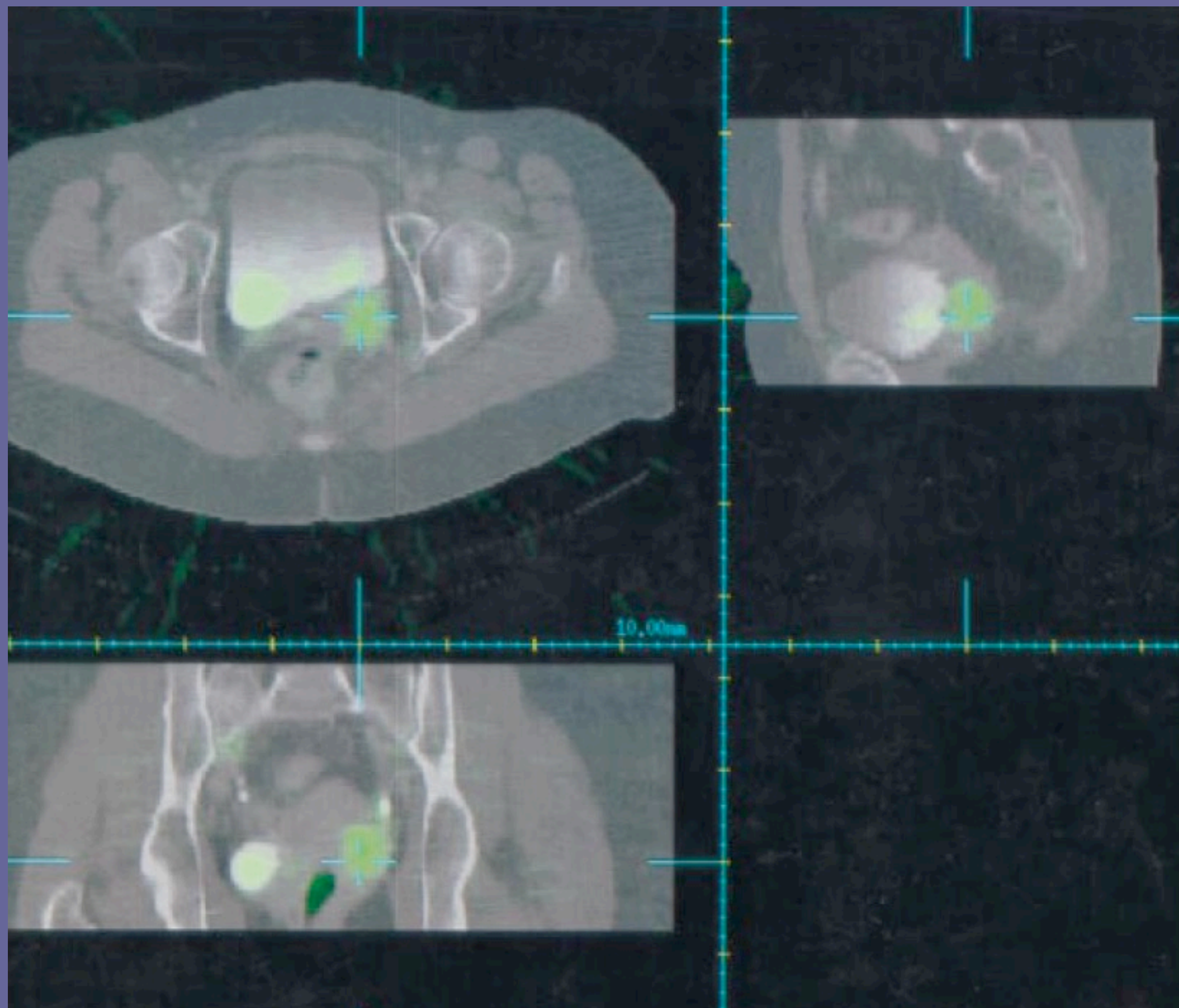
Image registration

- Registration = aligning image data
  - Corresponding physical points lie at the same image coordinates
- In the simplest case, two steps:
  - *Determination of corresponding points* in different images
    - Different times
    - Different imaging modalities
    - Different people
  - *Aligning corresponding points*

Image registration

- Provides a way to combine data across images
  - Without losing spatial specificity
  - An alternative to comparing segmented regions across images
- Simplifies analysis across images
  - Analyze change over time
    - Quantify tumor response to therapy
  - Combine different kinds of information
    - Add function from PET or SPECT to structure from MR or CT
  - Identify effects of disease
    - Do the average image data of patients differ from controls?
    - Group comparisons of brain atrophy
- Makes many quantitative methods of image analysis possible

CT + PET 18-FDG imaging of cervical cancer



Hawkes (1998)

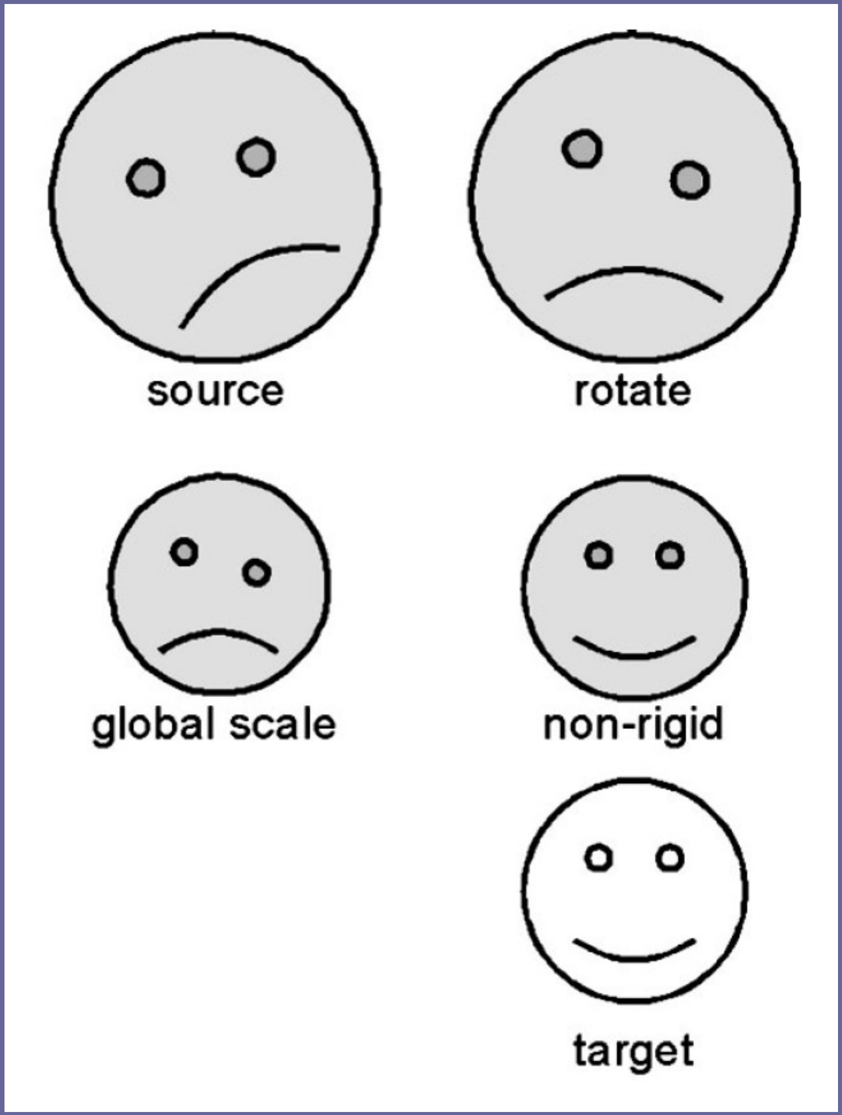
Structure in gray, 18-FDG activity in green

Classes of registration methods

- *Rigid transformations* preserve distances between points
  - Translation
  - Rotation
- *Affine transformations* take parallel lines into parallel lines
  - Includes rigid transformations
  - Scaling (stretching or shrinking)
  - Shearing
- Nonlinear warping

Goal of registration

- To determine the spatial transformation that maps positions in the *source* image to corresponding positions in a *target* image
- Generally consists of both rigid and non-rigid steps



Crum et al (2004)

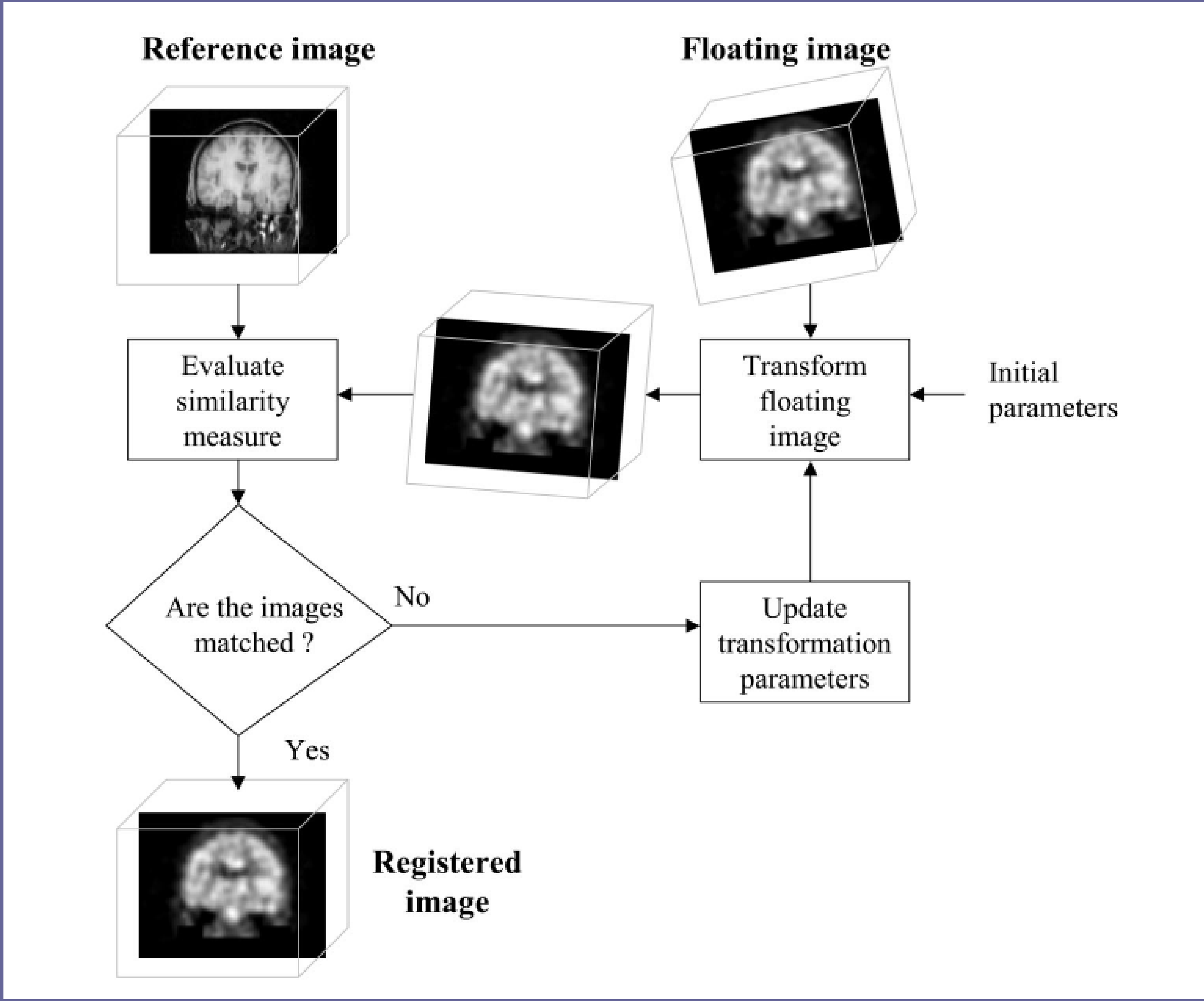
In-class exercise: what transformations are probably required?

1) Attenuation correction of PET images using a CT scan
2) Comparing images acquired before and after cancer treatment
3) Comparing the heart during contraction (systole) to the relaxed heart (diastole)

Components of registration methods

- A similarity measure
  - How well do source and target images match?
- A transformation model
  - Specifies the type of transformation that makes the source image match the target
    - Rigid
    - Non-rigid
  - Has free parameters that define particular solutions
- An optimization algorithm
  - Finds the parameters of the transformation that maximize similarity between the transformed source and the target

Target Source



Hutton and Braun (2003)

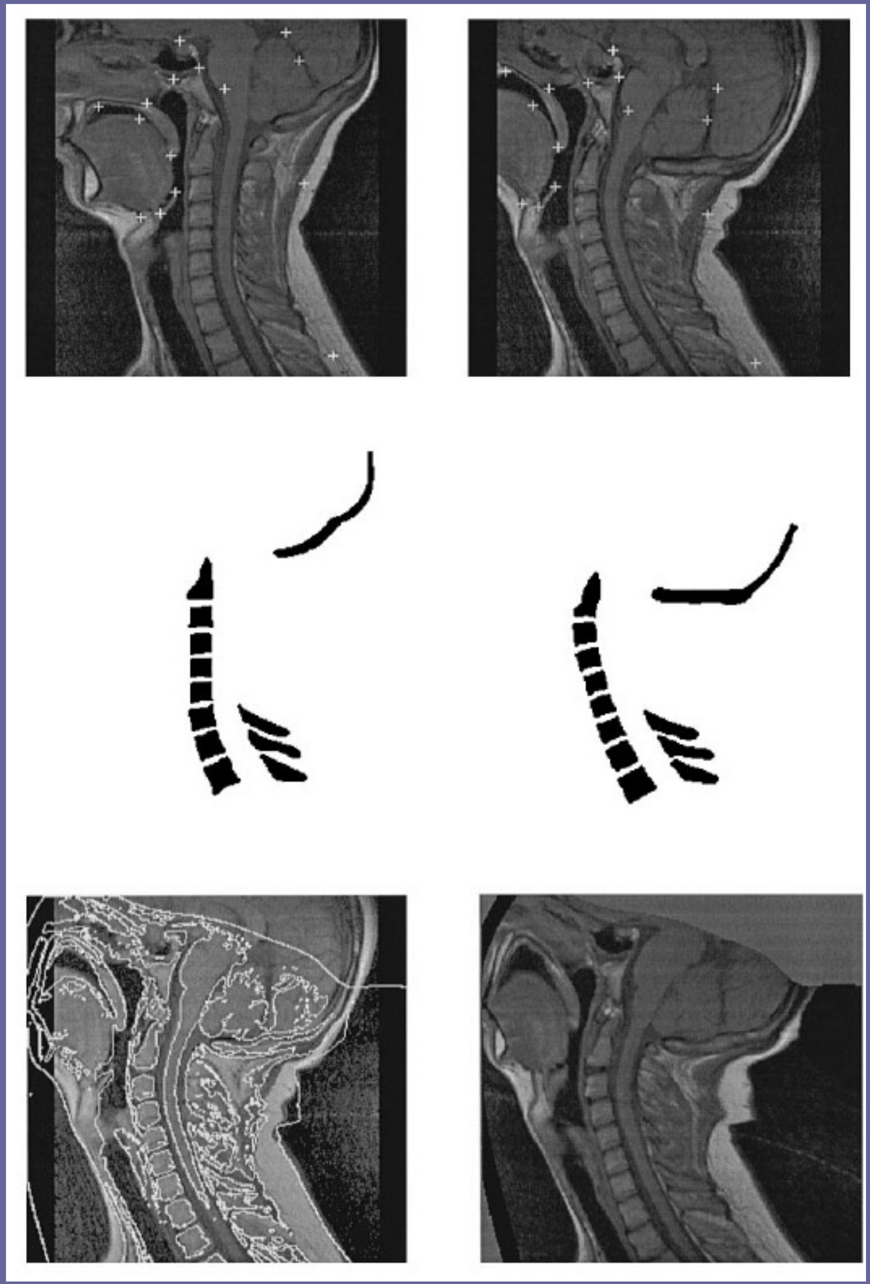
Similarity measures

- Geometric approaches
  - Best suited to high resolution anatomical modalities
  - Explicit models of anatomic elements
    - Surfaces, curves, point landmarks
    - Must be identified in both source and target images
  - Measure distances between geometric elements
- Intensity approaches
  - Measure similarity of intensity patterns in source and target
- Assume that similarity measure is maximized (or minimized) at the correct registration

Landmark identification

Source

Target



Edges of deformed image superimposed on target

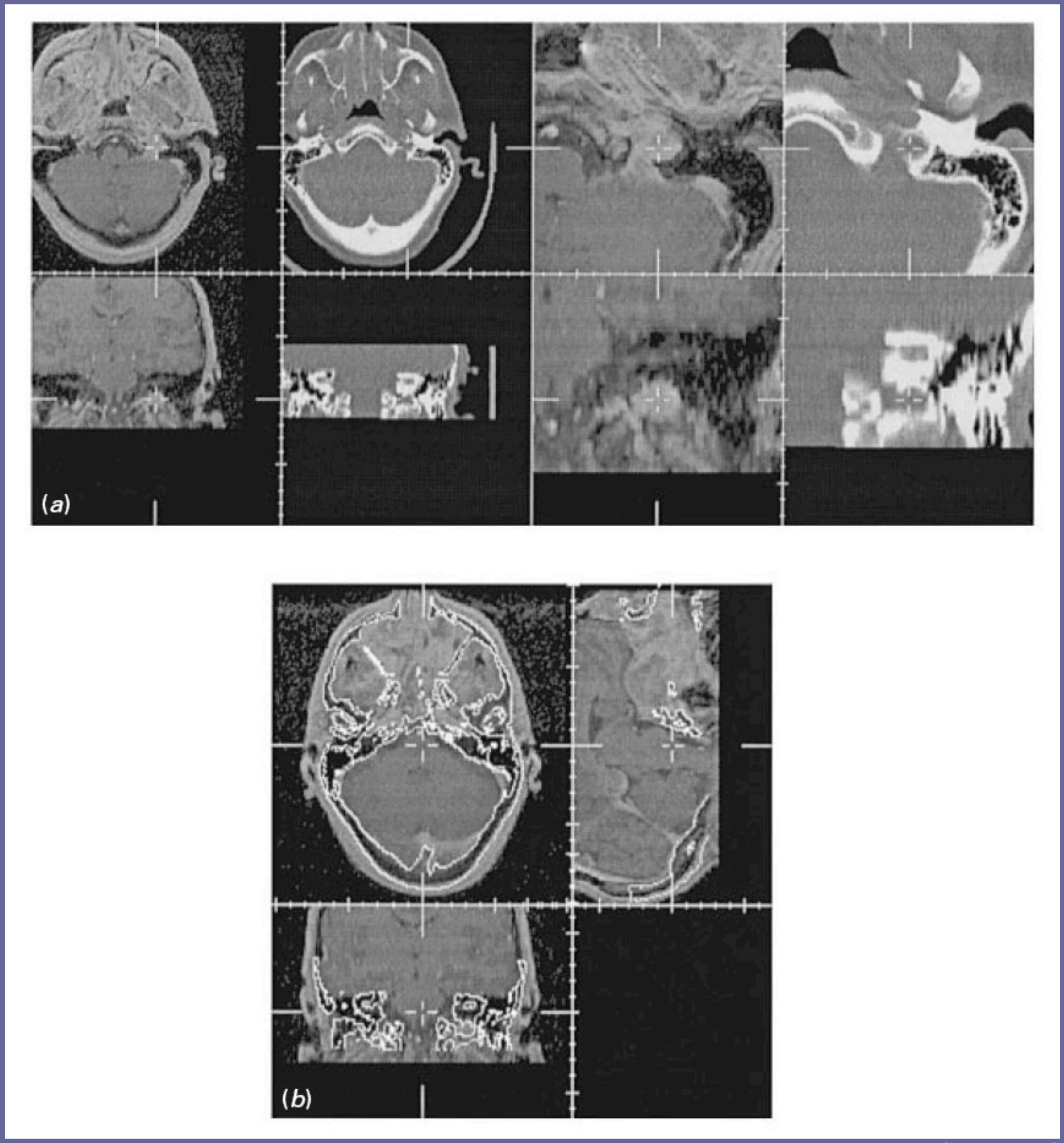
Deformed image

Hawkes (1998)

Choosing the similarity measure

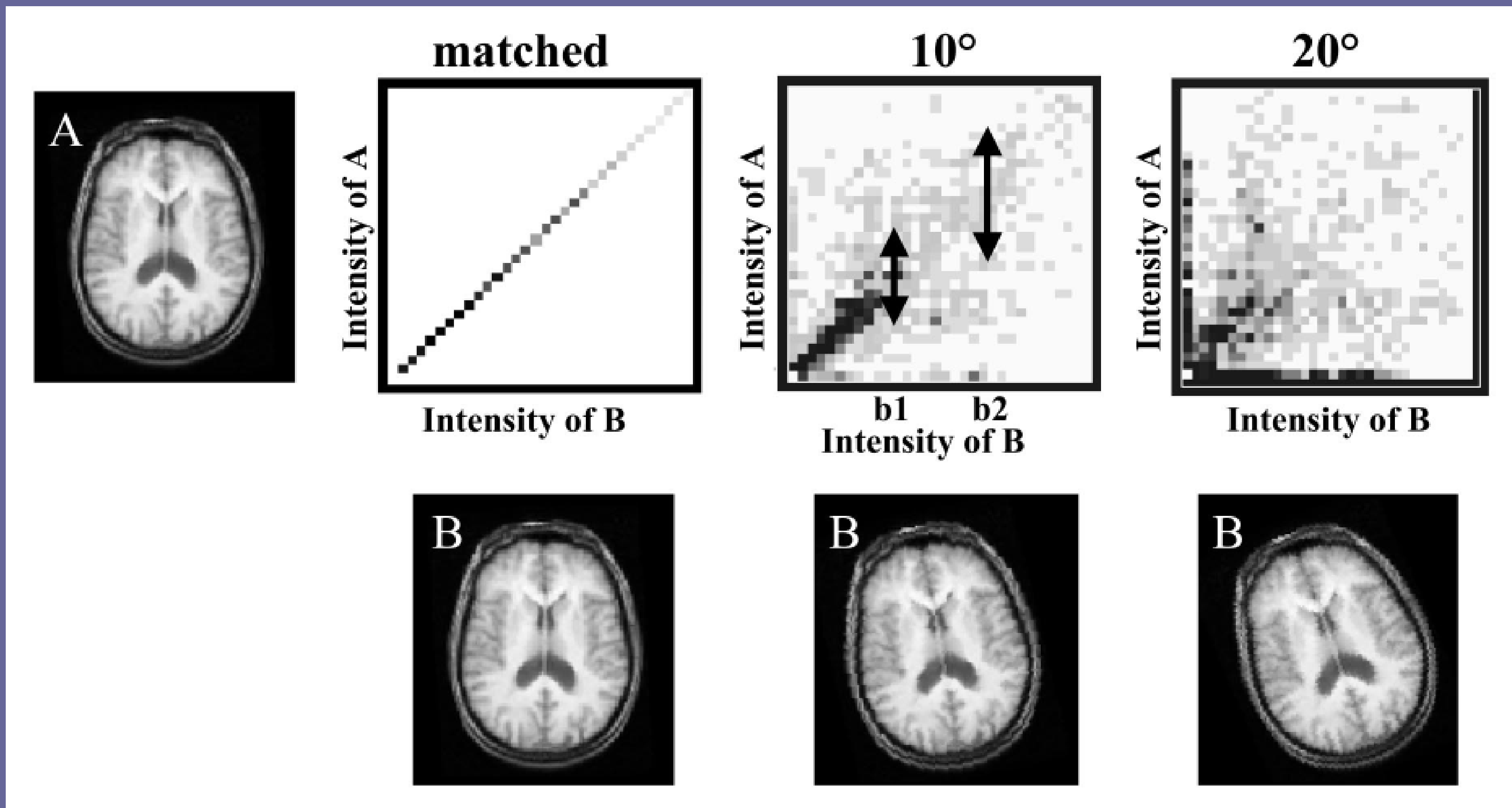
- Images differ only due to noise
  - Sum of squared intensity differences
- Image intensities are linearly correlated
  - Correlation coefficient
- Positions with similar intensities in the source also have similar intensities in the target
  - *Mutual information*
  - Allows for non-linear relationships between image intensities
  - Based on intensity histograms

CT superimposed on MRI



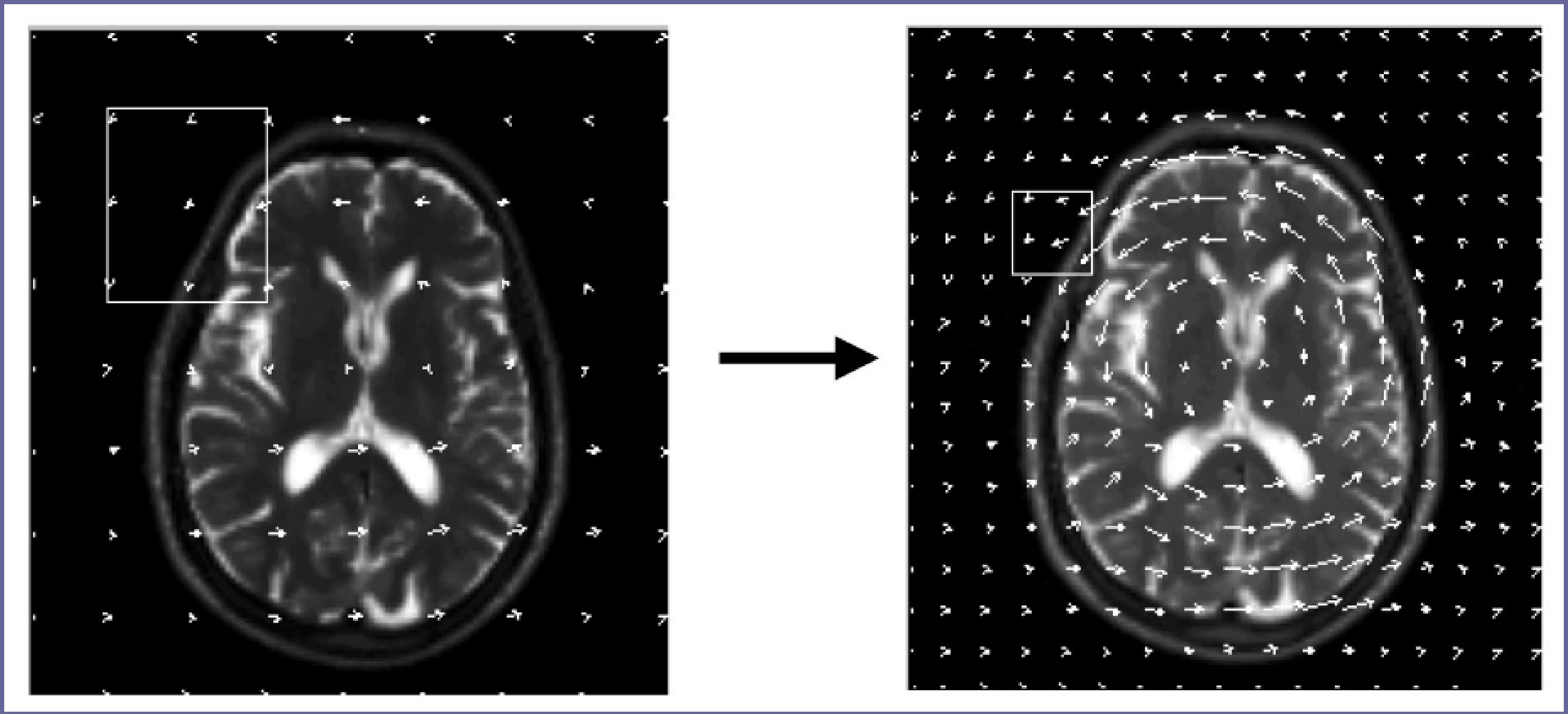
Hawkes (1998)

Joint intensity histogram



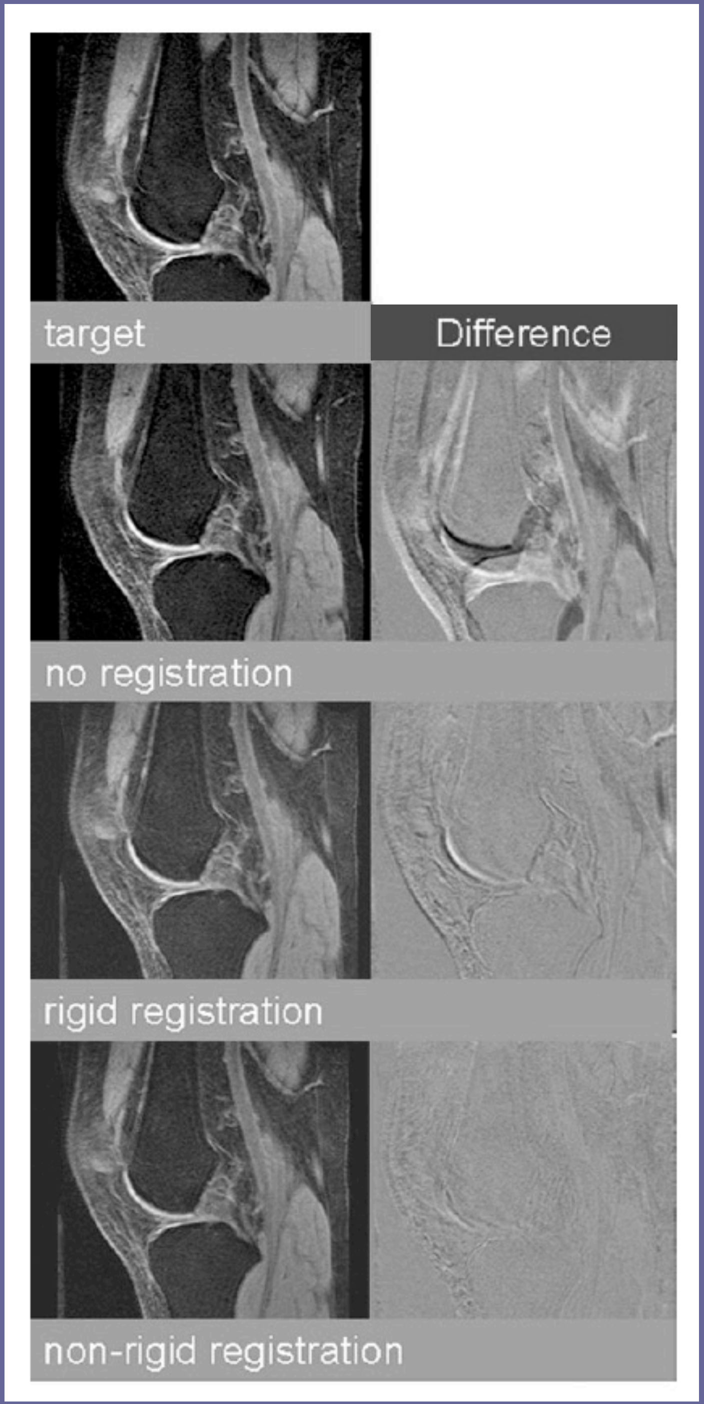
Hutton and Braun (2003)

Non-rigid registration based on local, rigid transformations



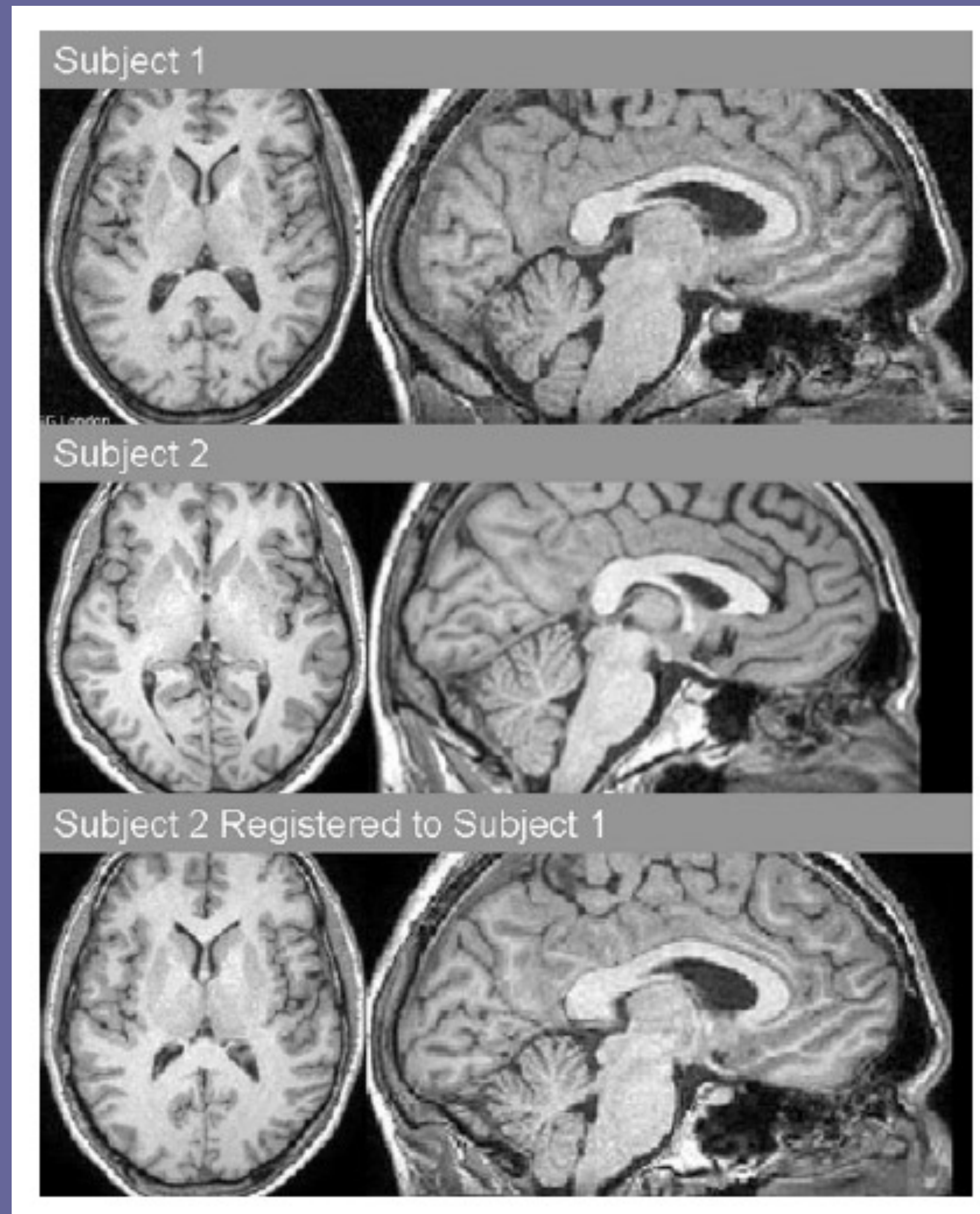
Hutton and Braun (2003)

Example 1: Tracking changes in cartilage thickness



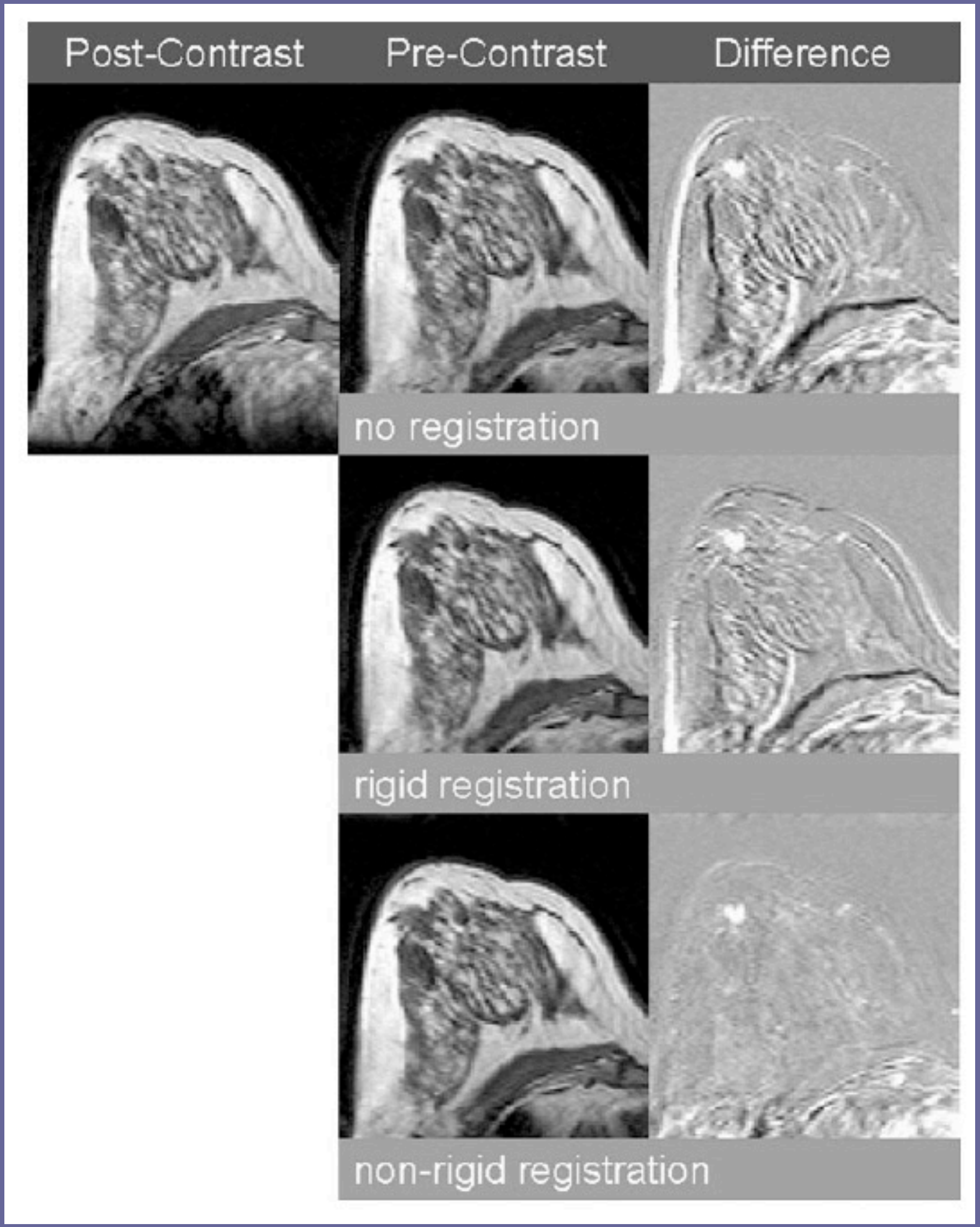
Crum et al (2004)

Example 2: Inter-subject brain matching



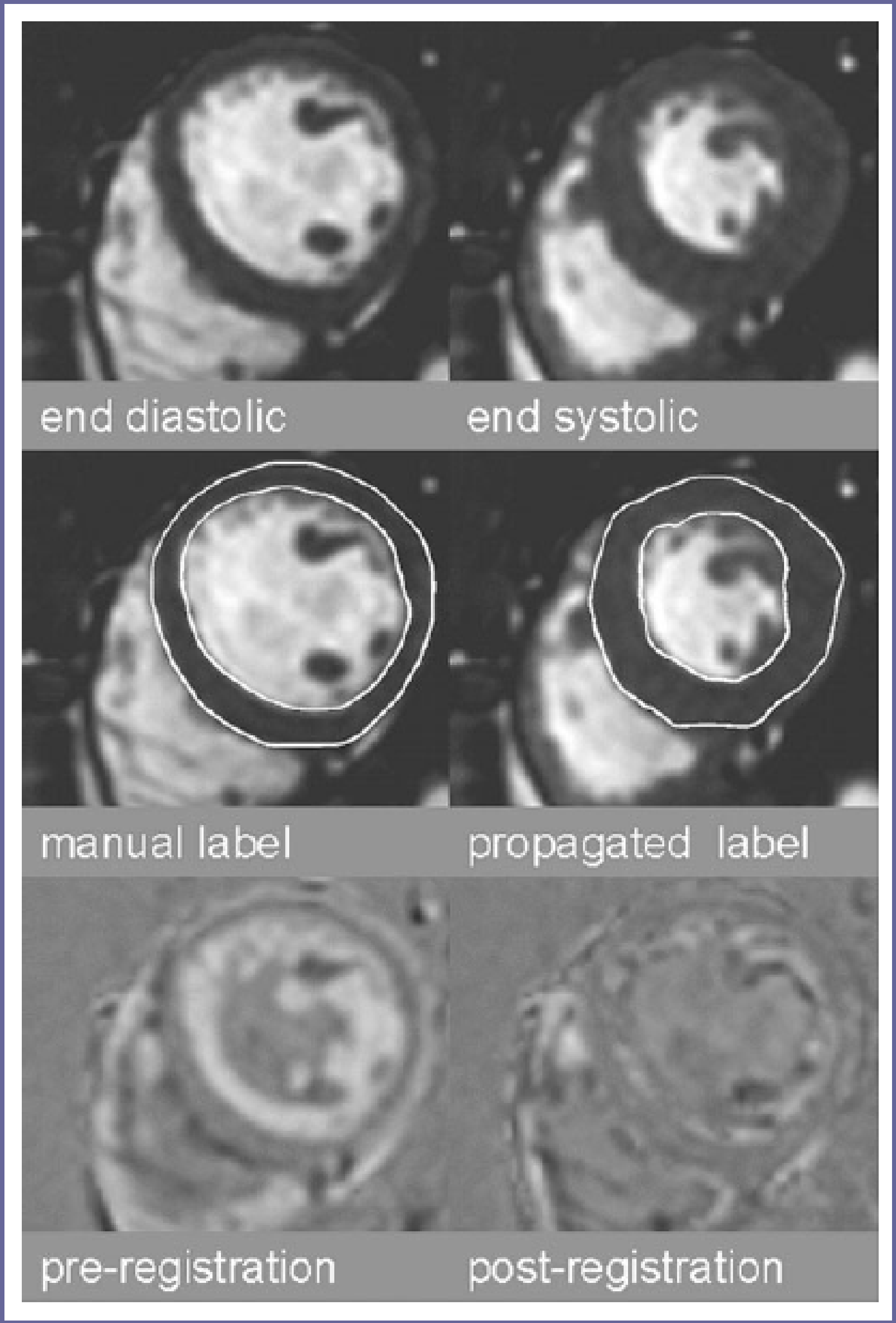
Crum et al (2004)

Example 3:
contrast-enhanced
mammography



Crum et al (2004)

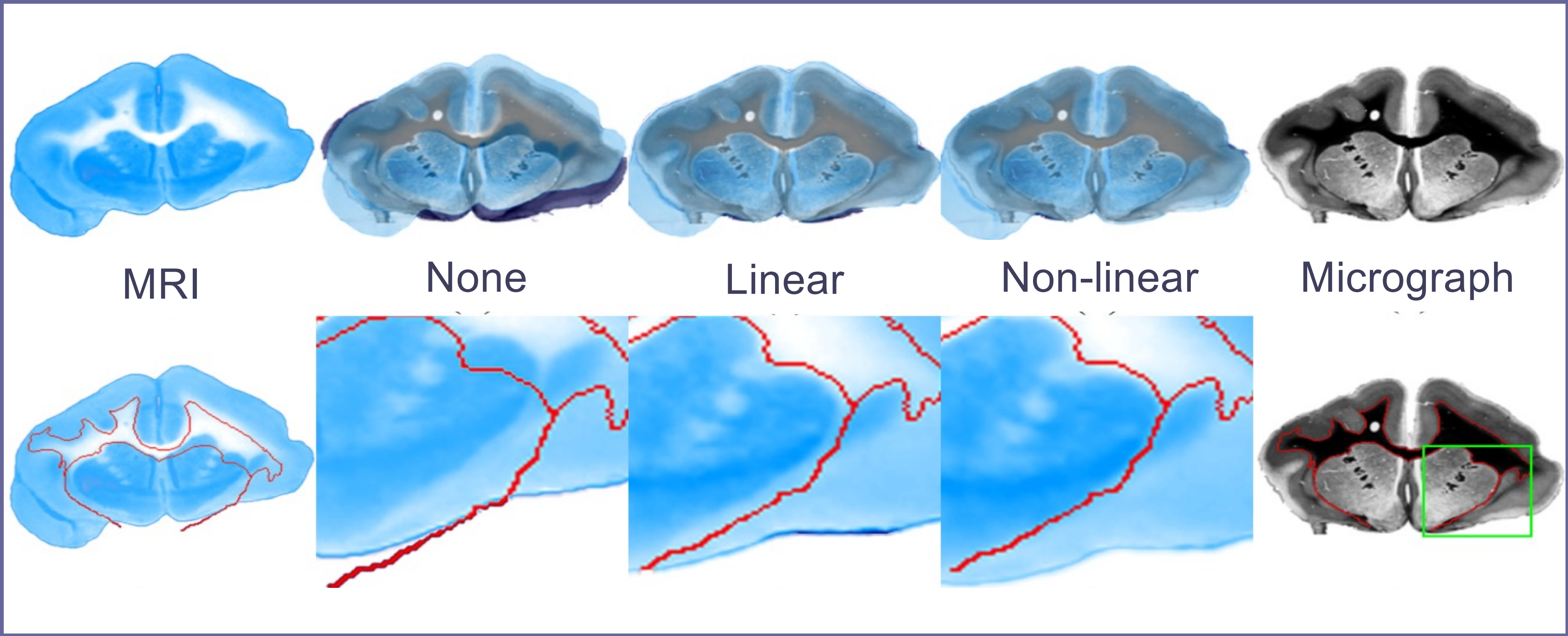
Example 4: myocardial segmentation



Crum et al (2004)

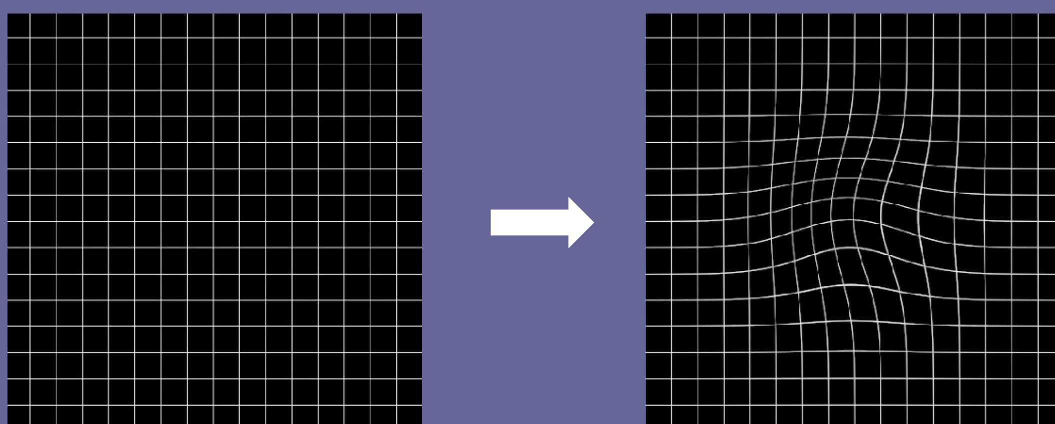
Example 5: MRI to light microscopy

- How is MRI data related to information in light microscopy?
- Section brain tissue and stain for specific molecules (e.g., myelin)



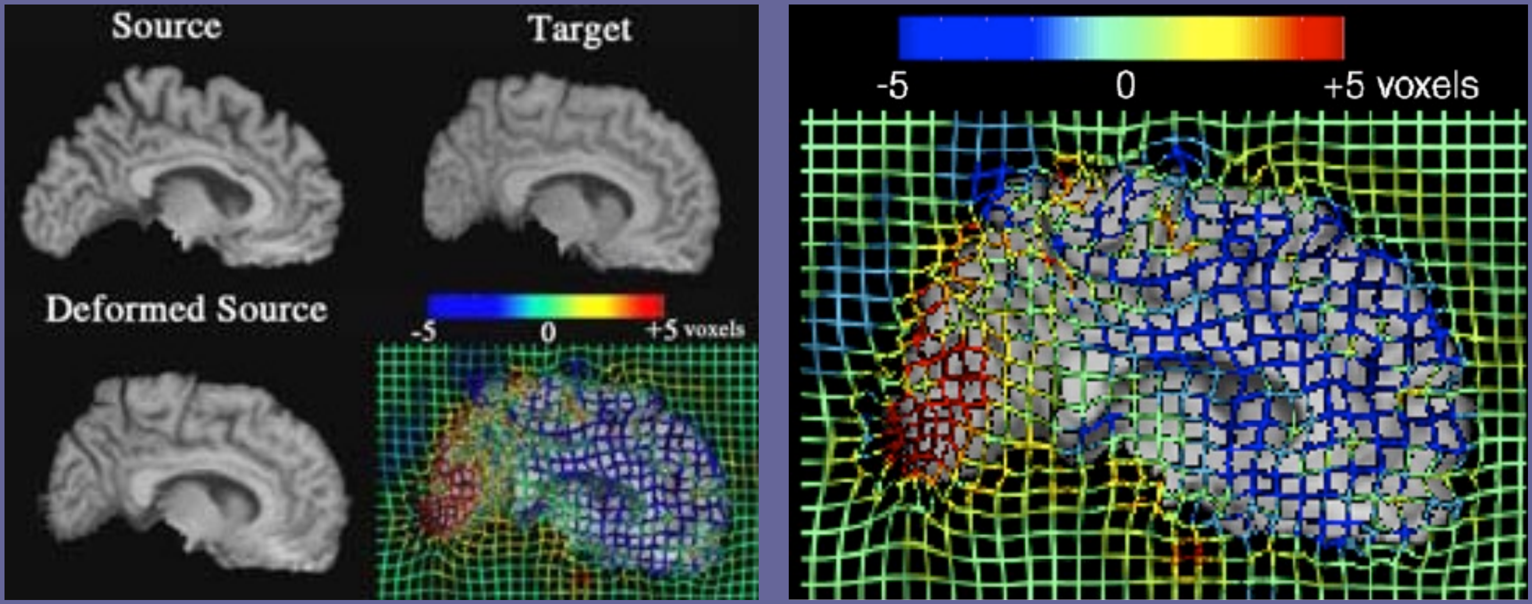
Use information from registration

- Image transformations contain useful information
  – Local increase or decrease in volume
  – Use this to compare local volume differences



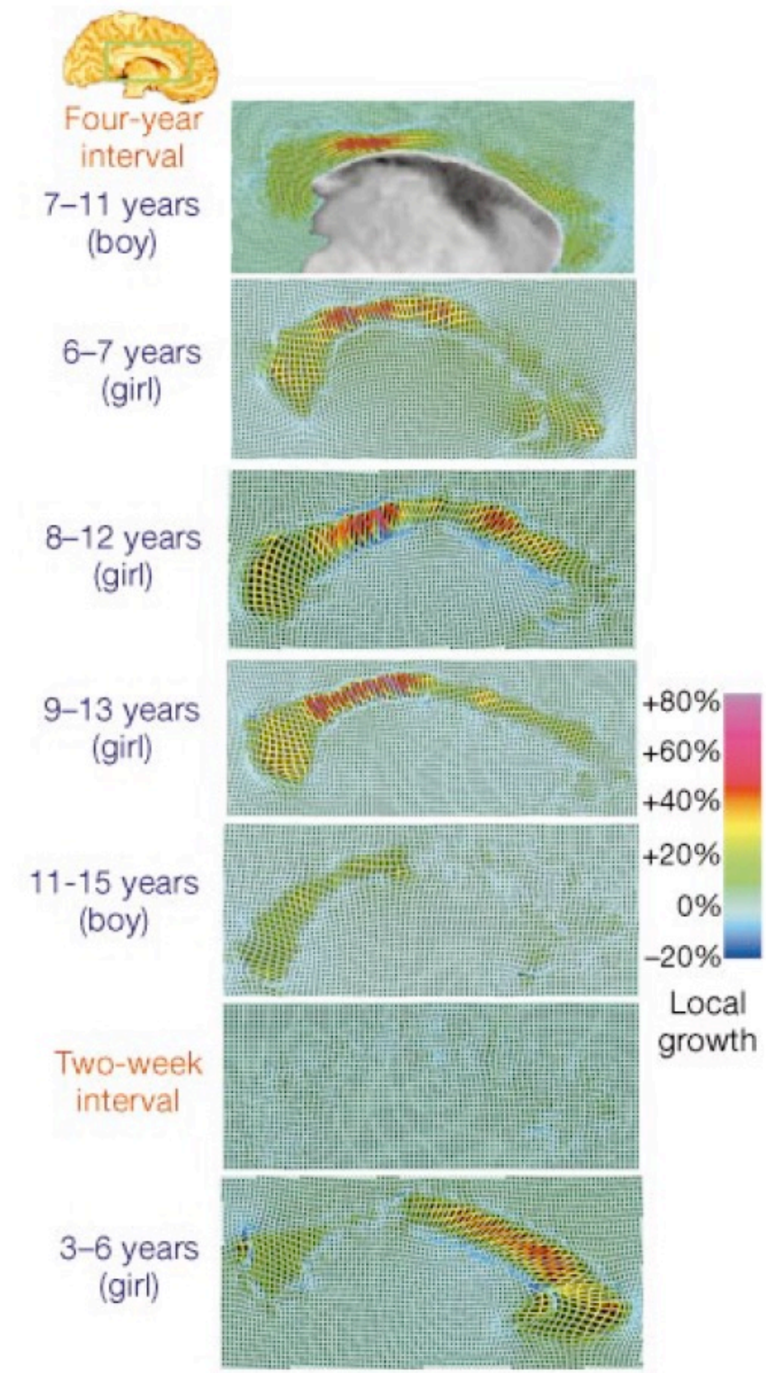
Applications to morphology

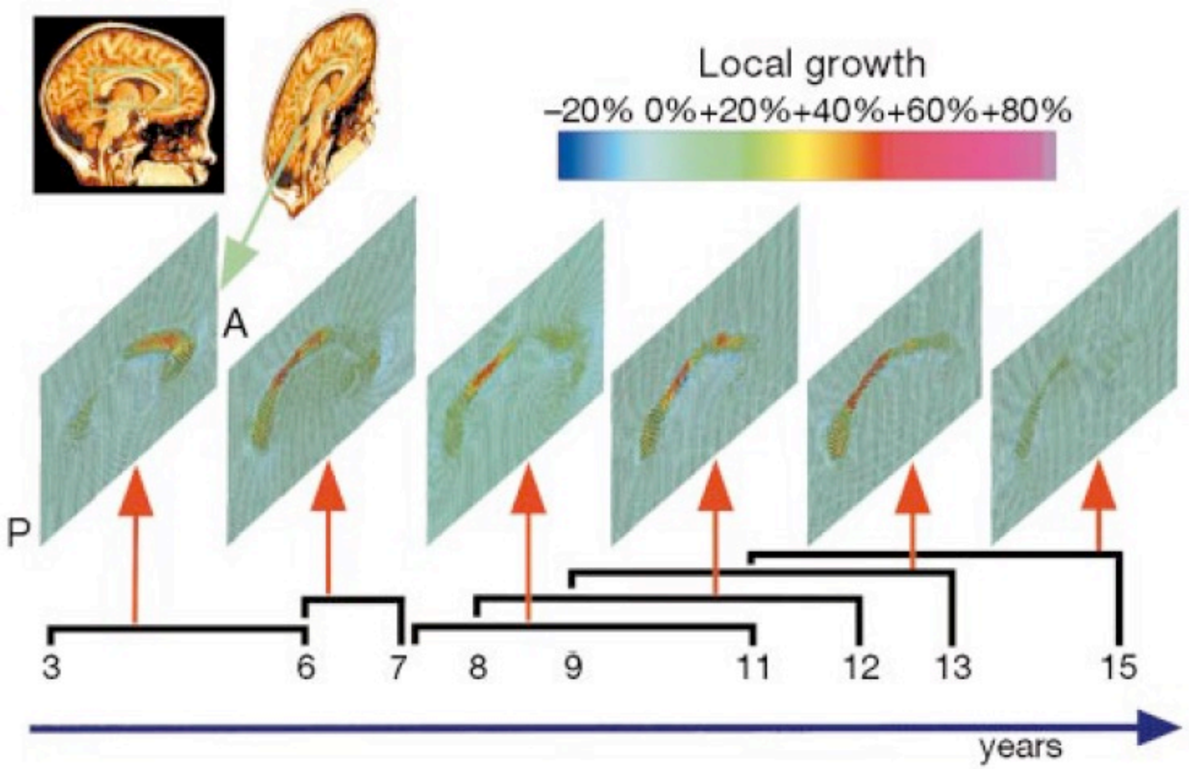
- Image registration may involve non-rigid transformations
  - Local increase or decrease in volume
  - Use this to compare local volume differences



Thompson (2007)

Measuring volume changes over time





Thompson (2000)

Example 6: motion correction

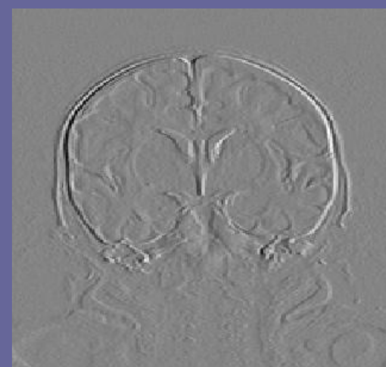
- Suppose the subject moves slightly between 2 images—how should the image intensity of the 2nd image (the source) be changed to match the 1st image (the target)?
- Image intensity is

$$I'(x,y) = I(x+\Delta x, y+\Delta y) = I(x,y) + \Delta x \frac{dI}{dx} + \Delta y \frac{dI}{dy} + \ldots$$

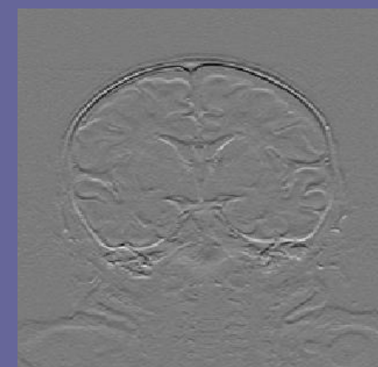
$$I'(x,y) - I(x,y) \approx \Delta x \frac{dI}{dx} + \Delta y \frac{dI}{dy}$$

How can we solve for Δx and Δy?

= Δx



$+\Delta y$



I' – I

dI/dx

dI/dy

- Writing

$$I'(x,y) - I(x,y) = \Delta x \frac{dI}{dx} + \Delta y \frac{dI}{dy}$$

for many image points (x_i,y_i) in a matrix equation:

$$\begin{pmatrix} I'(x_1,y_1) - I(x_1,y_1) \\ I'(x_2,y_2) - I(x_2,y_2) \\ \vdots \\ I'(x_N,y_N) - I(x_N,y_N) \end{pmatrix} = \begin{pmatrix} \left.\frac{dI}{dx}\right|_{x_1,y_1} & \left.\frac{dI}{dy}\right|_{x_1,y_1} \\ \left.\frac{dI}{dx}\right|_{x_2,y_2} & \left.\frac{dI}{dy}\right|_{x_2,y_2} \\ \vdots & \vdots \\ \left.\frac{dI}{dx}\right|_{x_N,y_N} & \left.\frac{dI}{dy}\right|_{x_N,y_N} \end{pmatrix} \cdot \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix}$$

Fitting for Δx and Δy provides an estimate of $I'(x,y)$ with the effects of motion removed.

Summary

- Registration aims to find corresponding points in two images.
- Makes possible more sophisticated image analysis
  - Combine data from different images
  - Analyze transformation for shape/volume changes
- A registration algorithm has 3 parts:
  - A similarity measure
  - A model for the transformation
  - An optimization algorithm
- Typically large scale features are registered better than small ones—active area of research

References

- Crum WR, Hartkens T, Hill DLG. Non-rigid image registration: theory and practice. The British Journal of Radiology 77:S140-S153 (2004).
- Hawkes DJ. Algorithms for radiological image registration and their clinical application. J. Anat. 193: 347-361 (1998).
- Hutton BF, Braun M. Software for Image Registration: Algorithms, Accuracy, Efficacy. Seminars in Nuclear Medicine, 33(3): 180-192 (2003).