MACHINE
VISION
GROUP

Multi-modality Medical Image Registration

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Introduction

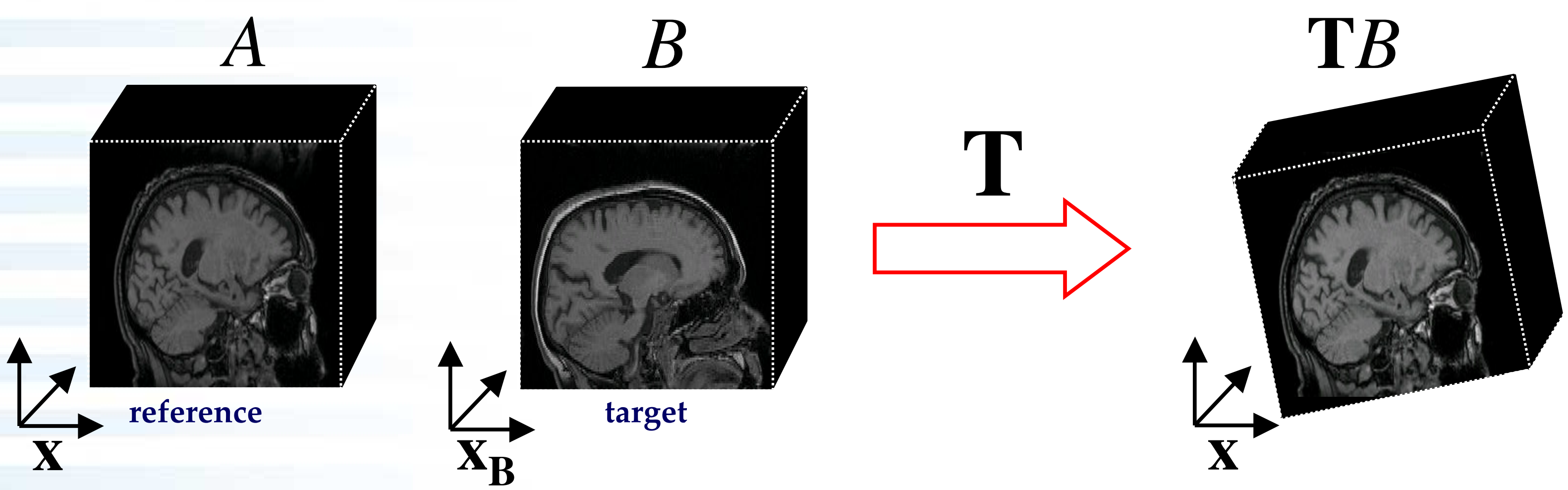
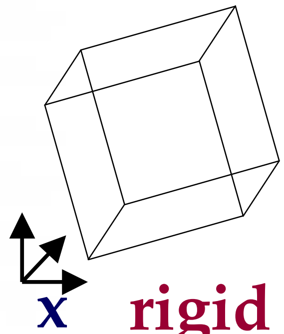


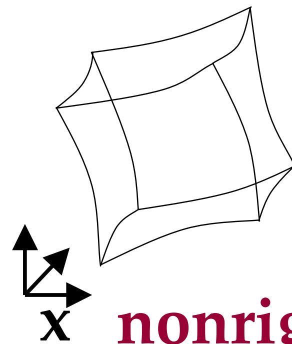
Image registration is a process of finding optimal geometric transformation (T) that puts two images into spatial correspondence.

Classification

Rigidity:



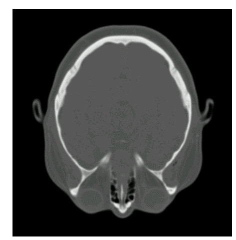
rigid



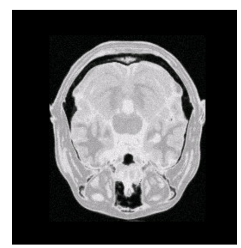
nonrigid

Modality:

mono-modality



multy-modality

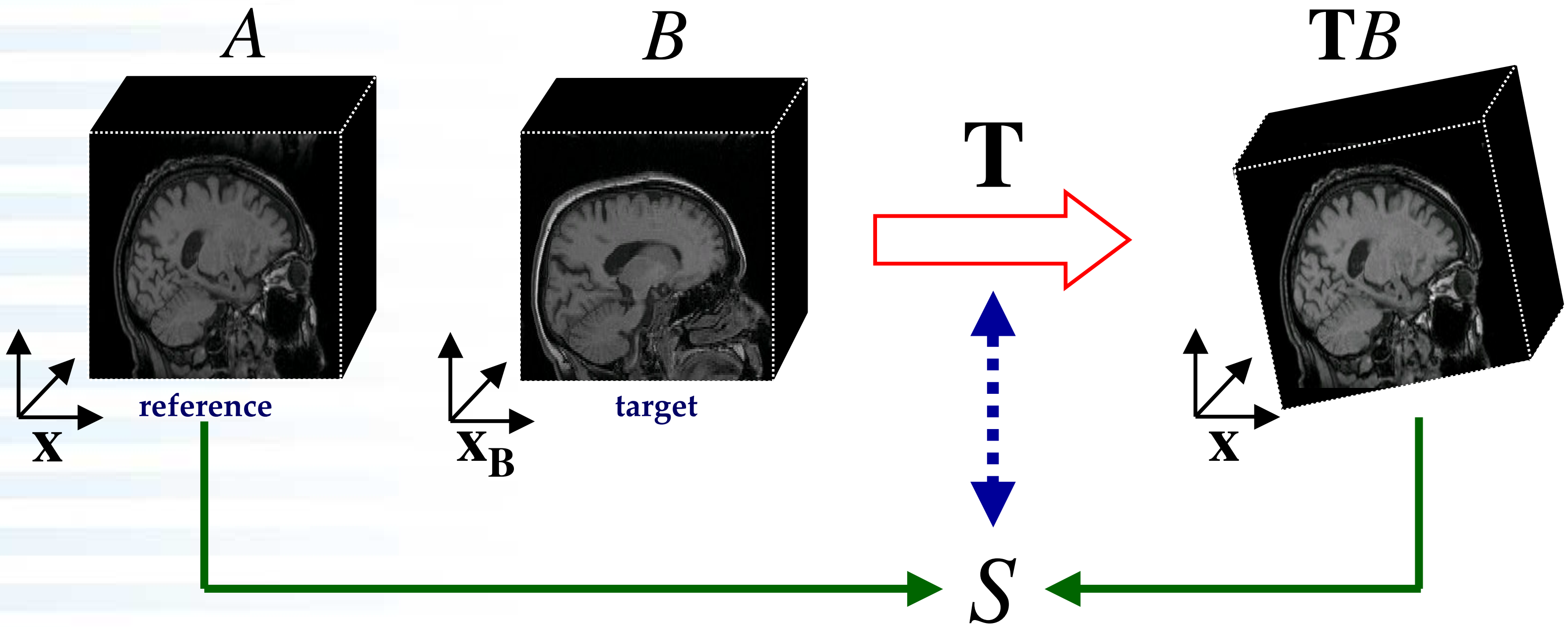


Features: geometric / intensity

Applications

- Image information analysis
  - image comparison
  - image fusion
- Image geometry analysis
  - analysis of tissue deformation
  - analysis of organ activitiy
- Image segmentation
  - Image to atlas registration

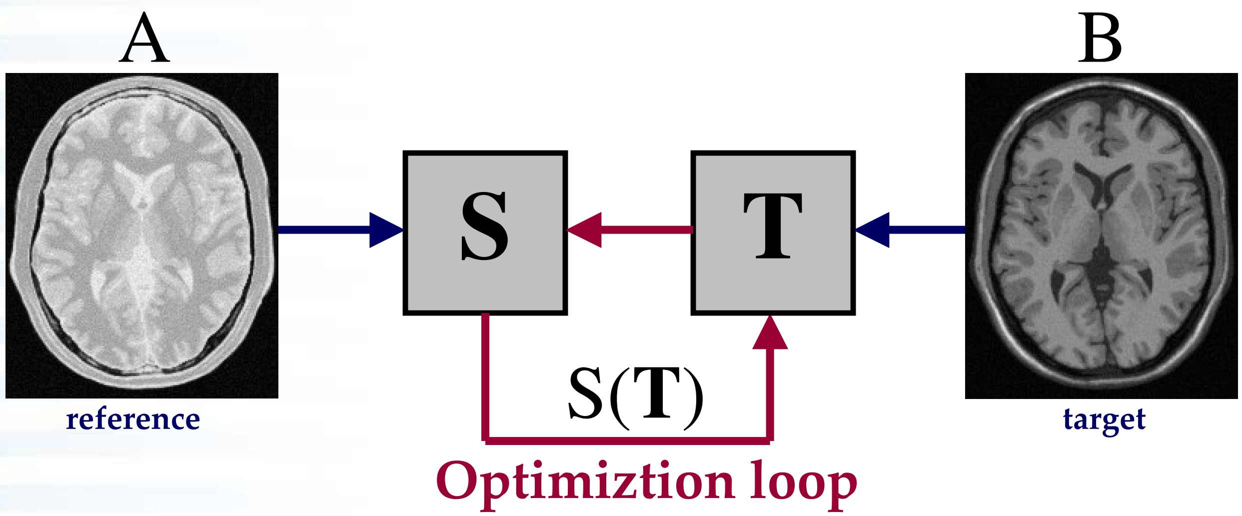
Approach



Registration is an opimization process of finding such transformation that maximizs image similarity

(considering geometric limitations of spatial deformation model).

Parametric reg. process



Global: 3D rigid: 6 parameters

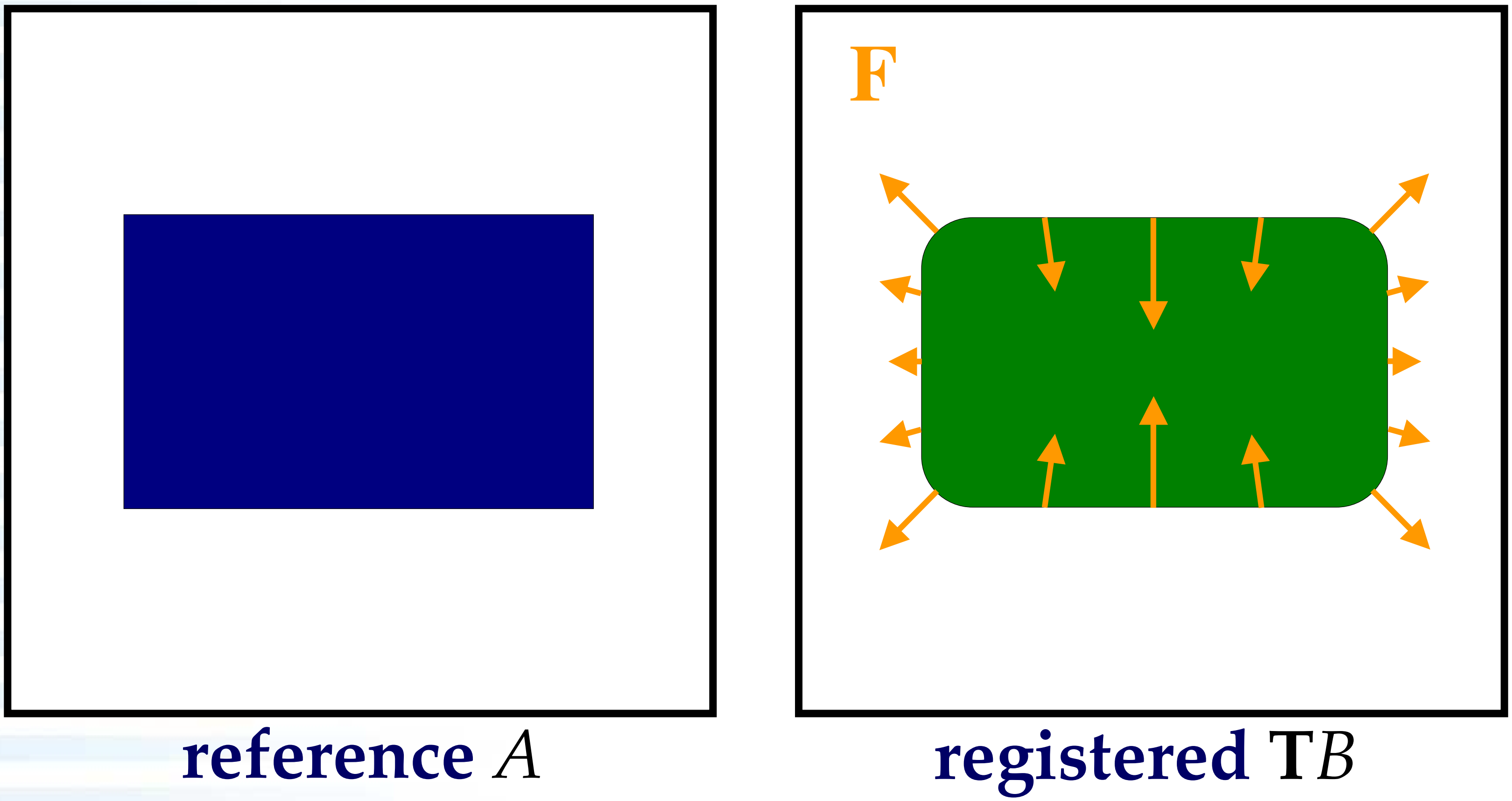
3D affine: 12 parameters

...

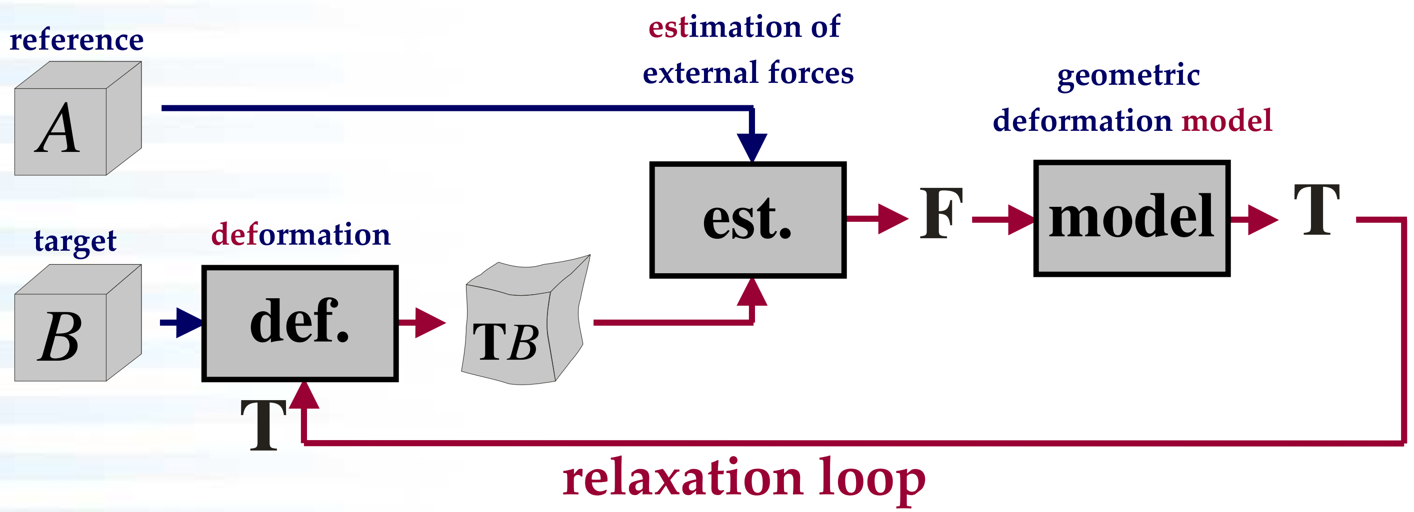
Local: splines...

High-dim. registration

Continuum mechanic registration



High-dim. registration



Transformation is given as voxel displacenets.

Ext. forces tend to maximize image similarity.

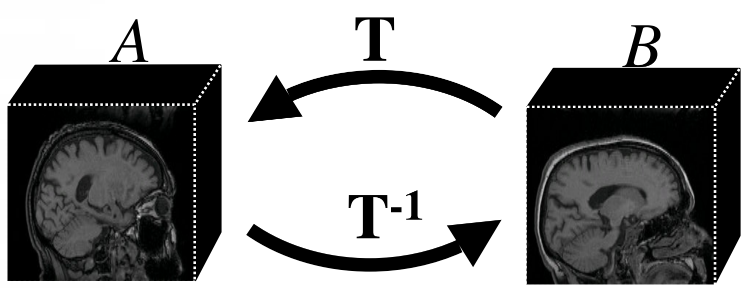
Geometric deformation model maps the ext. forces into a new (improved) transformation.

External forces

- Obtained as gradients of image similarity with respect to transformation:

$$F = \frac{\partial S(A, \mathbf{T}B)}{\partial \mathbf{T}}$$

Similarity measurement is asymmetric...

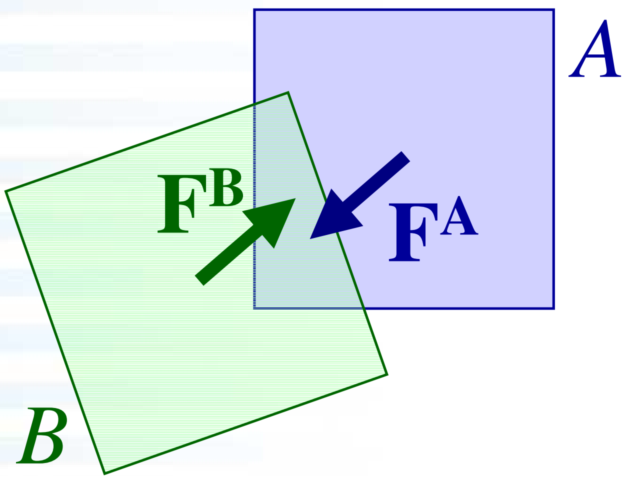


$$S(A, \mathbf{T}B) \neq S(\mathbf{T}^{-1}A, B)$$

...leading to inverse inconsistency of registration!

Proposed solution: “Symmetric image registration”.

Symmetric reg. approach



Images are treated equaly.

External forces are computed for both images and act between the images.

Newton's 3rd law of motion (action reaction):

$$\mathbf{F}^A = -\mathbf{F}^B$$

The forces are symmetric!

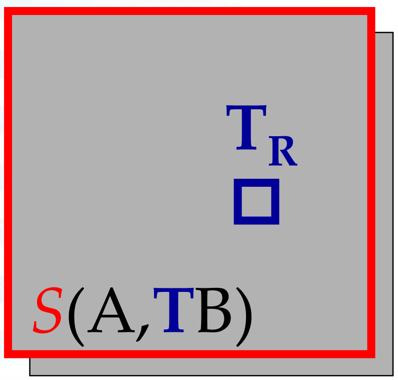
Similarity metrics

- Mono-modality:
  - MSD (mean square distance)
  - CC (correlation coefficient)
- Multi-modality
  - MI (mutual information)
  - NMI (normalised mutual information)

Multi-modality and locality

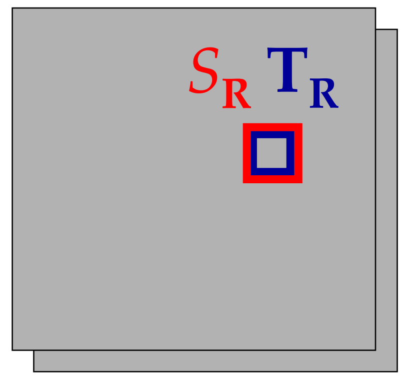
Detection of local image discrepancies:

Measuring global similarity:



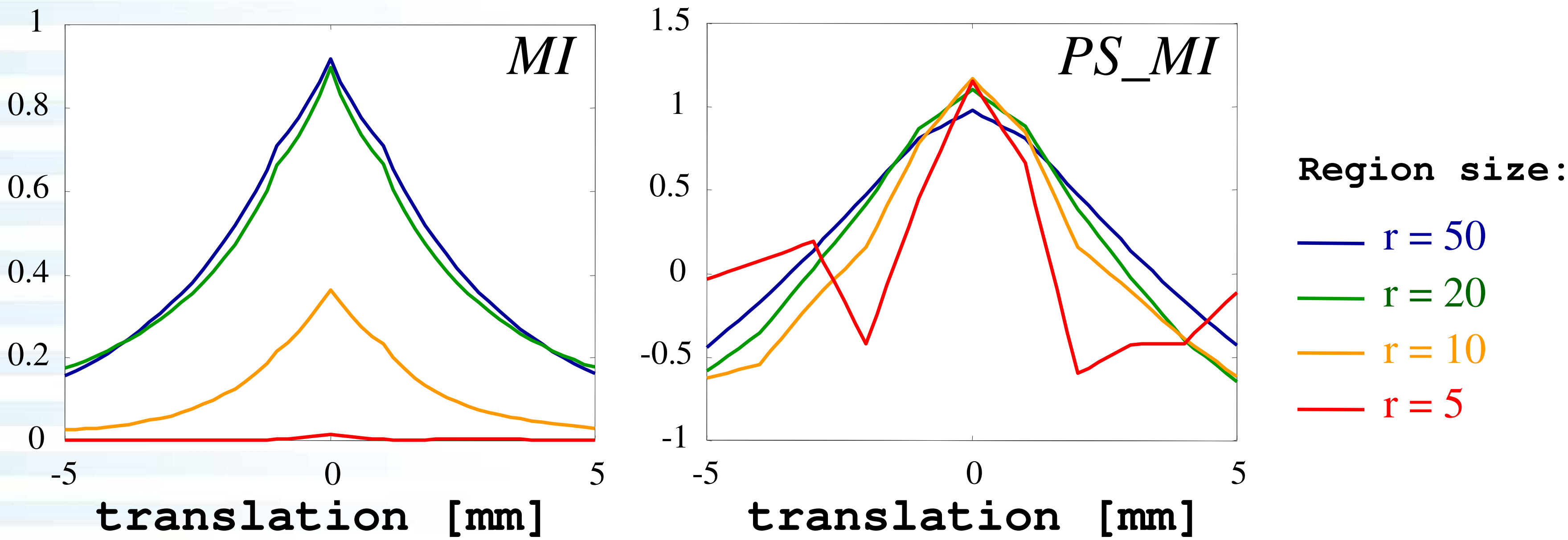
High computational cost in practice limits the dimensionality and registration precision.

Measuring local similarities



Statistical multi-modality similarity measures are limited to large image regions.

Locality and multi-modality



Proposed solution: "point similarity measures".

PS_MI : point similarity measure based on MI

Point similarity measures

Procedure, MI example:

- Global estimation of intensity dependance between images:

$$f_{MI}(\mathbf{i}) = \log \frac{p(\mathbf{i})}{p(i_A)\,p(i_B)}$$

- Local (point) similarity measurement

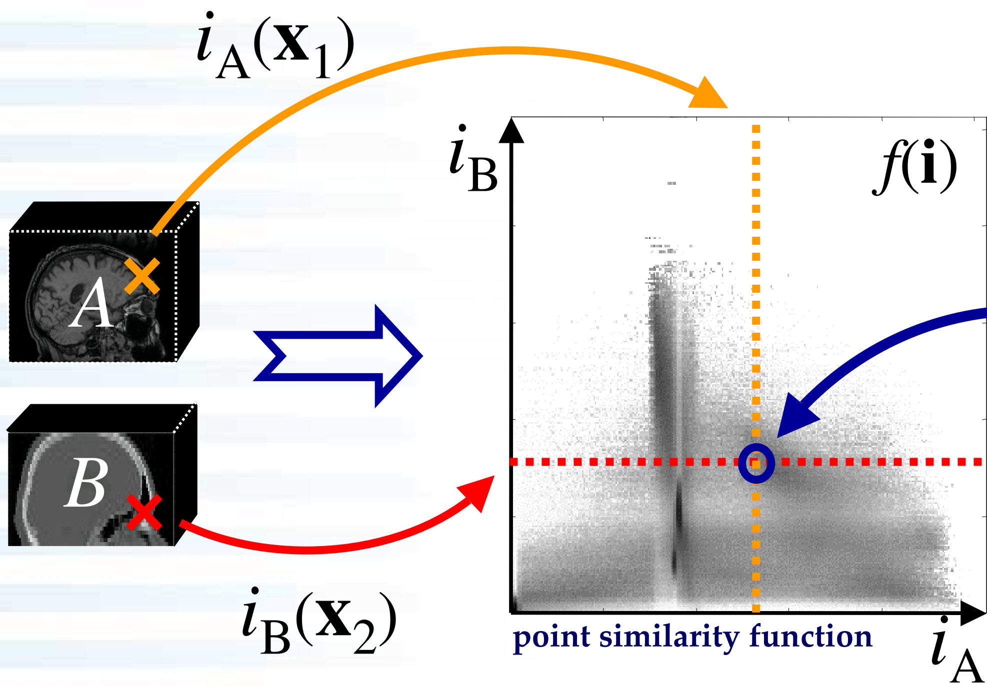
$$S_{MI}(\mathbf{x}_1,\mathbf{x}_2) = f_{MI}\big(\mathbf{i}(\mathbf{x}_1,\mathbf{x}_2)\big)$$

- Eventual averaging (locality dependent)

$$MI = \overline{S_{MI}(\mathbf{x})}$$

Point similarity measures

Procedure, MI example: $f_{MI}(\mathbf{i}) = \log \dfrac{p(\mathbf{i})}{p(i_A)\,p(i_B)}$



Similarity of points:

$$f_{MI}\,(i_A, i_B) = S_{MI}\,(\mathbf{x}_1, \mathbf{x}_2)$$

Similarity of a region:

$$S_R = \overline{S_{MI}(\mathbf{x},\mathbf{x})}\,\Big|_{\mathbf{x}\in R}$$

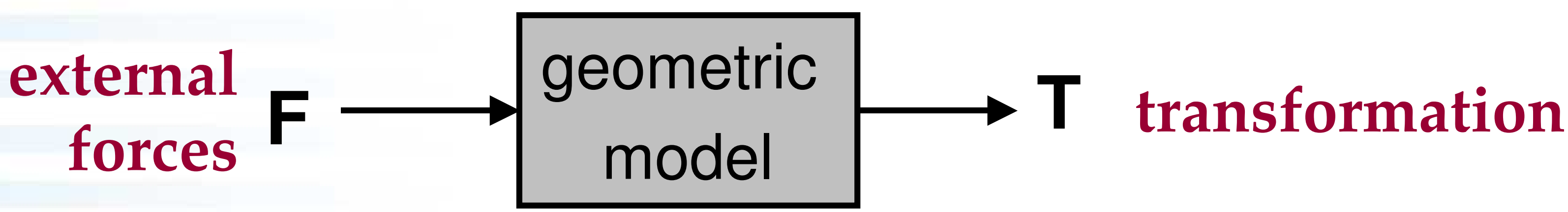
Similarity of whole images: $MI = \overline{S_{MI}(\mathbf{x},\mathbf{x})}$

Benefits

- **Locality**
  (also for multi-modality measures)
- **Low computational cost**
  (similarity function serves as a LUT)
- **Solution to interpolation artefacts**
  (when using interpoaltion of similarity).
- **Accuracy and robustness**
  (variety of methods for computing similarity functions)
- **Ability to use prior knowledge**
  (prior knowledge in intensity domain)
- **...**

Geometric models

- Geometric models define the space of admissible transformations (deformations).
- I the case of high dimensional registration they define the relationship between external forces and consequent transformation.



- Because image deformation should follow deformation of real objects/tissues, physical deformation properties are often used, e.g., elasticity, viscousity...

Realistic def. models

- Sources of unrealisticity:
  - Simplifications of physical deformation properties and usage of unrealistic models.
  - Usage of homogenious deformation models.
  - External forces (obtained as gradients of image similarity) are not realistic!
- Realistic models may not be optimal!

Geometric models

Implementations:

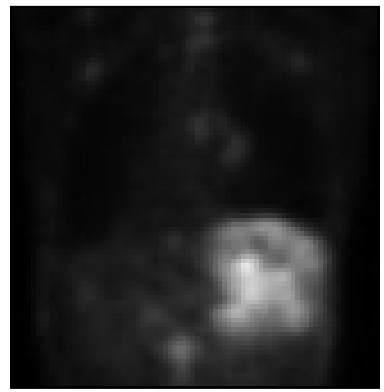
- **Solution of elastic PDE** (Broit and Bajcsy, 1981)
- **Finite-element method** (Gee et al., 1994)
- **Elastic convolution kernel** (Bro-Nielsen, Gramkow 1996)
- **Simplifications: separable kernels,** e.g. Gaussian.
- **Important physical characteristics may be obtained by additional constraints** (e.g., volume preservation...)
- **Inhomogeneous models** (different tissues modeled differently, with different properties or different models)

Examples (1)

CT / PET image fusion:

CT

PET-tr

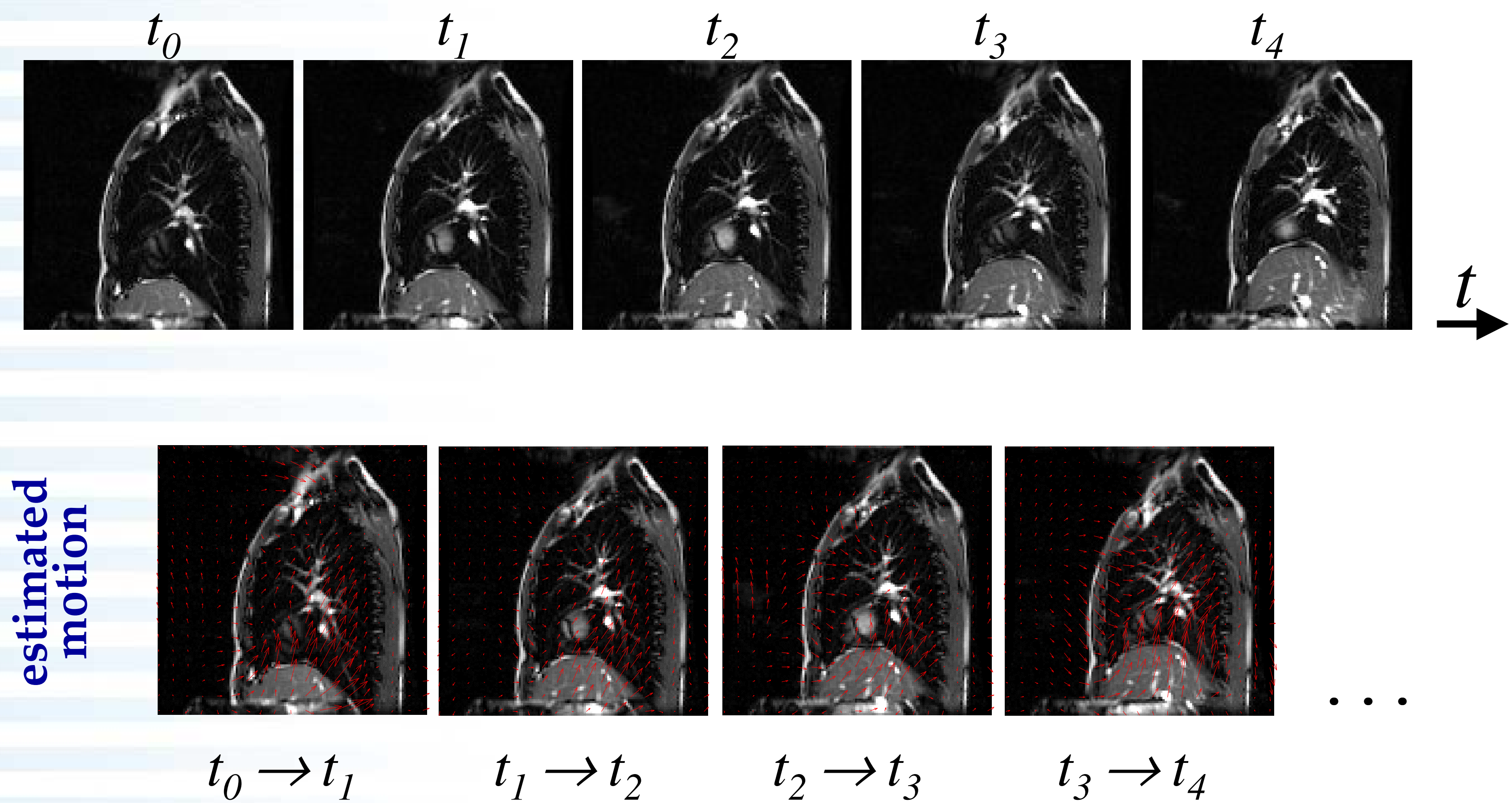


PET-em

combined
CT and PET-em

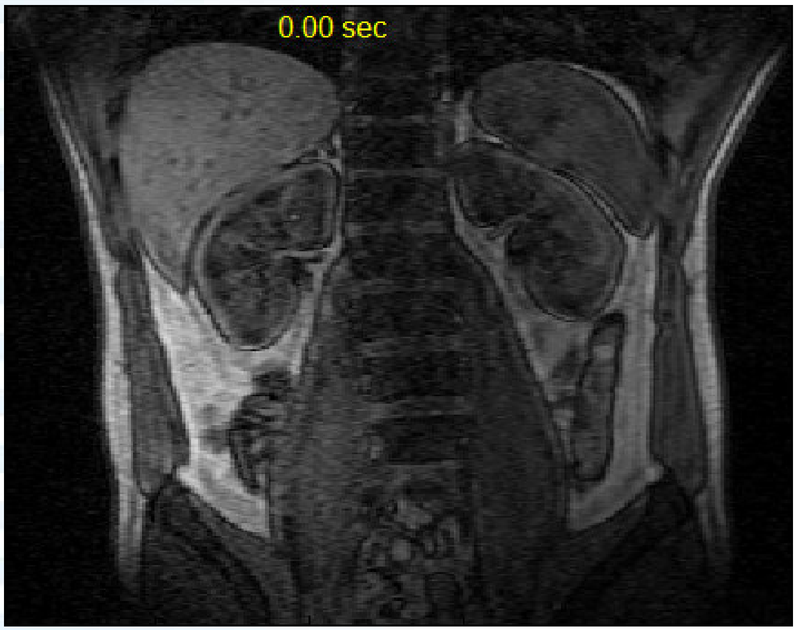
Examples (2)

Breathing motion analysis

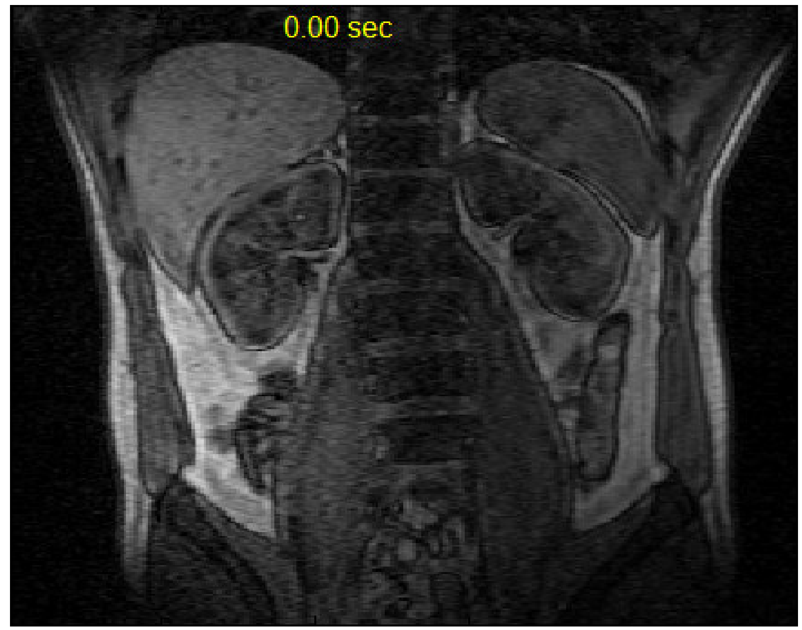


Examples (3)

Registration of kidney time series



original



registered

A collaborative work related to the Kidney MRI project at University of Bergen

Conclusion

- Medical image registration can contribute to a broad range of medical procedures ,e.g., to medical diagnostics, treatment planning, surgeries, radiotherapy...
- The interest of medicine is increasing.
- Lots of possibilities for improving registration by integrating prior knowledge, i.e., anatomical knowledge and knowledge related to image formation.

http://vision.fe.uni-lj.si

Papers:

Symmetric image registration:

- Peter Rogelj, Stanislav Kovačič. "Symmetric Image Registration". *Medical Image Analysis*, 10(3): 484-493, June 2006.

Point similarity measures:

- Peter Rogelj, Stanislav Kovačič, James C. Gee. "Point similarity measures for non-rigid registration of multi-modal data". *Computer Vision and Image Understanding*, 92(1): 112-140, October 2003.
- Peter Rogelj, Stanislav Kovačič."Point similarity measure based on mutual information". In: James C. Gee, J. B. Antoine Maintz, Michael W. Vannier (eds.), *Biomedical Image Registration : revised papers*, (Lecture notes in computer science, vol.2717), pp.112-121. Springer-Verlag, June 2003.
- Peter Rogelj, Stanislav Kovačič."Rigid multi-modality registration of medical images using point similarity measures". In: O. Drbohlav (ed.), *Proceedings of the 8th Computer Vision Winter Workshop CVWW'03*, pp.159-163. February 2003.

Deformation models:

- Peter Rogelj, Stanislav Kovačič."Spatial deformation models for non-rigid image registration". *CVWW'04* , pp.79-88, February 2004.

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