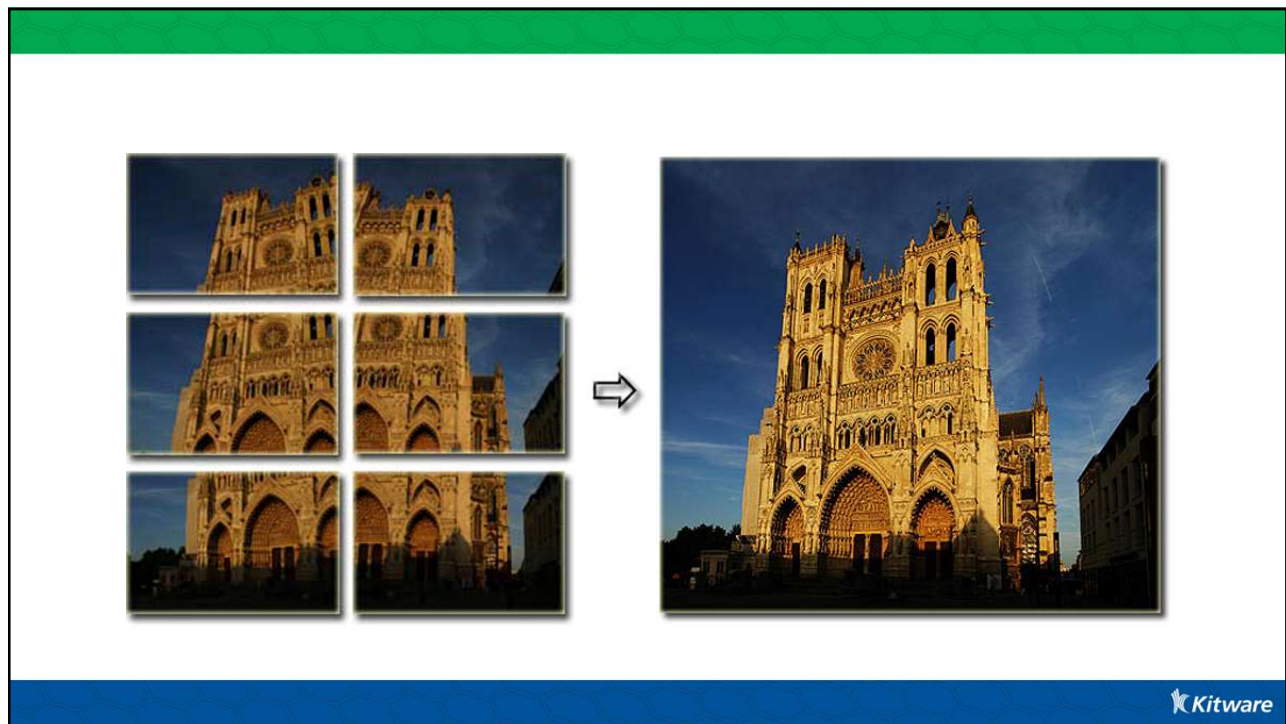


# Recalage

Module Image – CPE Lyon

*Julien Jomier*

## Qu'est ce que le recalage?



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4

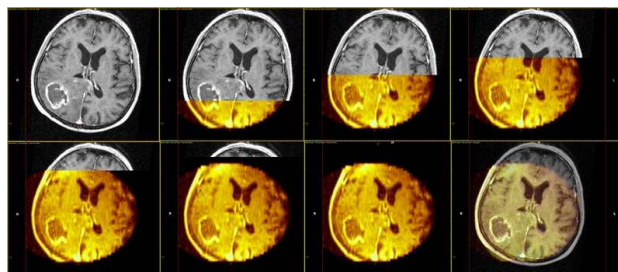


## Articles Récents (MICCAI 2020)

- MvMM-RegNet: A new image registration framework based on multivariate mixture model and neural network estimation
- Database Annotation with few Examples: An Atlas-based Framework using Diffeomorphic Registration of 3D trees
- Large Deformation Diffeomorphic Image Registration with Laplacian Pyramid Networks
- Flexible Bayesian Modelling for Nonlinear Image Registration
- Cross-Modality Multi-Atlas Segmentation Using Deep Neural Networks

## Recalage

Technique qui consiste en la **mise en correspondance** d'images (ou modèles) afin de pouvoir les **comparer** ou **combiner** leurs informations respectives.



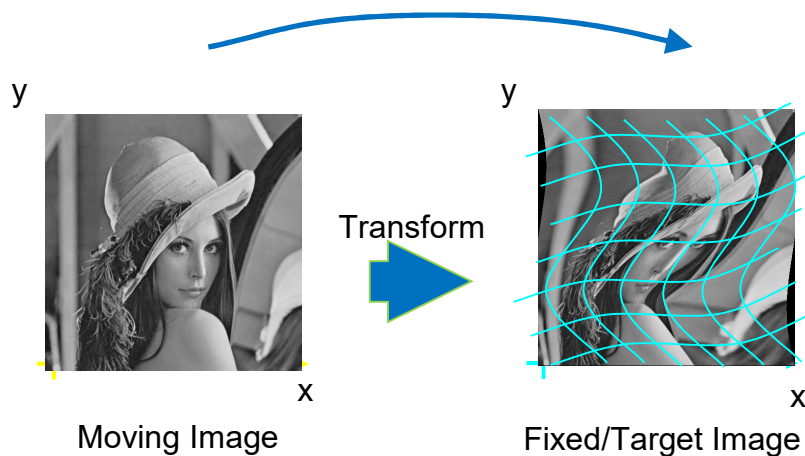
## Plan

- Éléments des algorithmes de recalage
- Exemples d'utilisation
- TP

## Composants du recalage

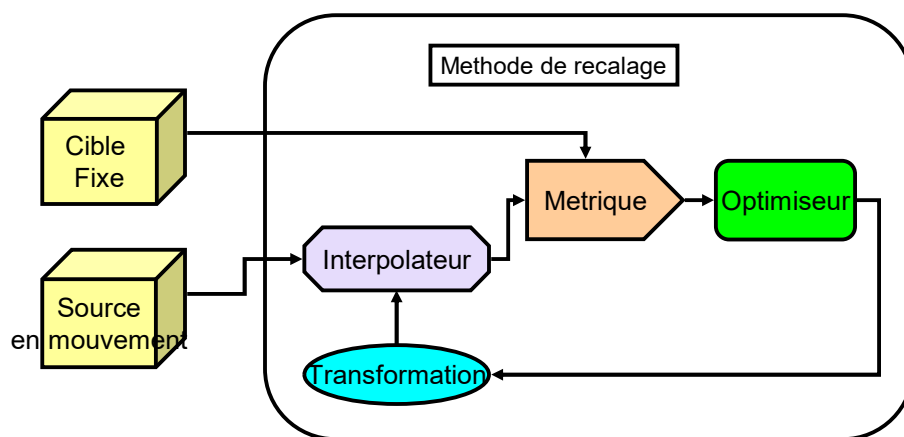
- Transformation
- Métrique
- Optimiseur
- Interpolateur

# Composants du recalage



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## Composants du recalage



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## Composants du recalage

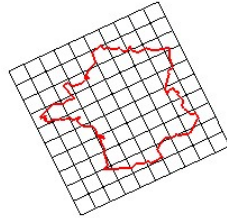
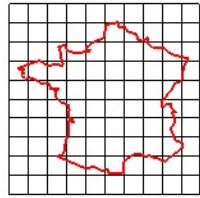
- Transformation
- Métrique
- Optimiseur
- Interpolateur

## Transformations

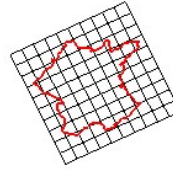
- **Translations** (déplacements)
  - conserve distances et angles orientés
- **Rotations** (isométrie)
  - conserve distances et angles
- **Homothéties** (similitude)
  - conserve les rapports entre les distances
- **Affinités**
  - conserve le parallélisme
- **Non-Linéaires**



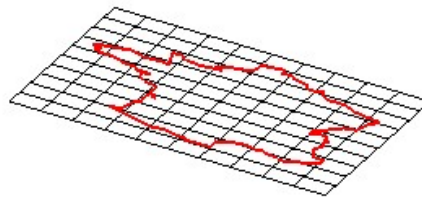
## Transformations



isometrie



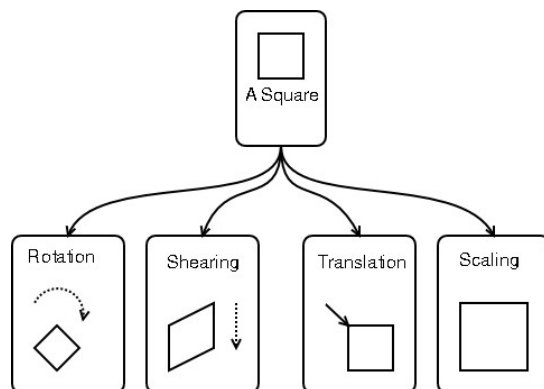
similitude



Affine

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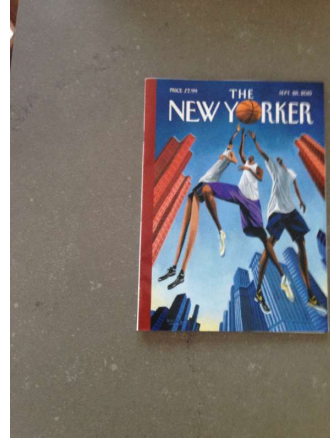
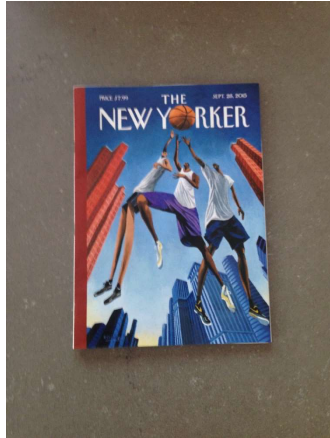
## Affinité



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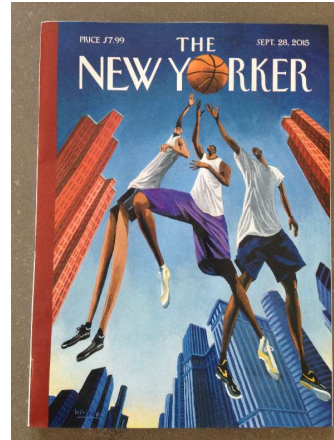


Quelle transformation?



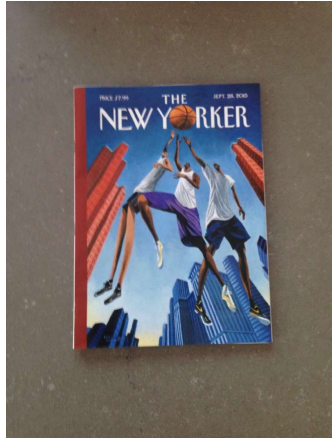
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Quelle transformation?

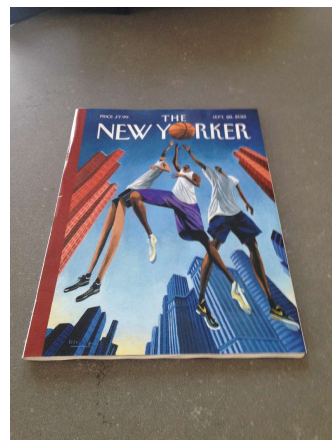


18

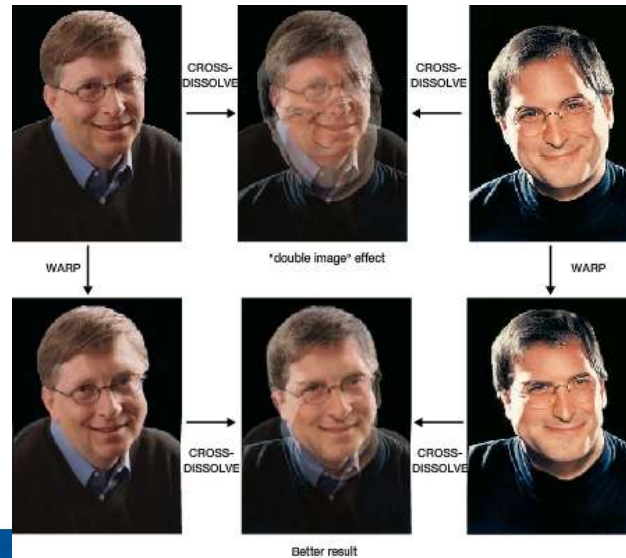
Quelle transformation?



Quelle transformation?



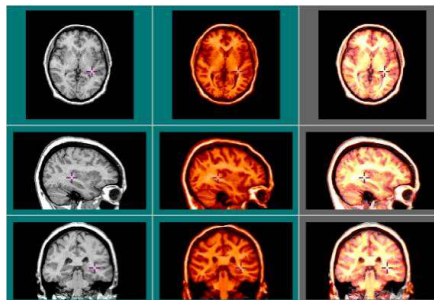
## Transformations Non-Lineaires



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## Transformations Non-Linéaires

- Transformations élastiques ou non-rigides
- Exemples:
  - B-Splines (Combinaison linéaire de Spline)
  - Thin-plate splines



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## Composants du recalage

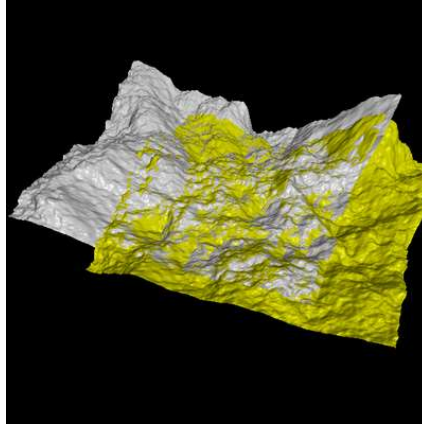
- Transformation
- Métrique
- Optimiseur
- Interpolateur

## Métriques

- Mesure de similarité(s) entre la cible fixe et la source en mouvement.
- **Recalage géométrique**
  - distances
  - Iterative Closest Point
- **Recalage iconique**
  - Somme des différences au carré
  - Coefficient de corrélation
  - Information mutuelle

## Métrique: Iterative Closest Point

- Alignement de surfaces ou de nuages de points



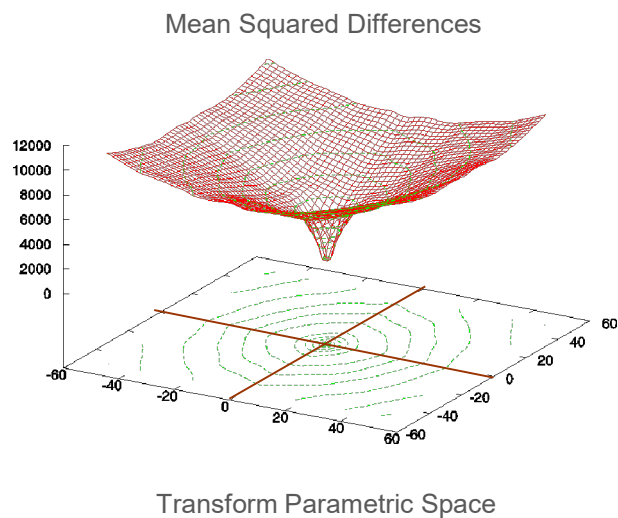
## Métrique: Iterative Closest Point

- **Algorithme simple et rapide**
  - Pour chaque point du model on trouve le point le plus proche
  - On calcule la moyenne des distances
  - On transforme le nuage de points
  - On réitère jusqu'à convergence: la moyenne des distance diminue
- **Problèmes?**

## Métrique: SSD

- $\sum_{x,y} (f(x,y) - t(x-u, y-v))^2$
- Probleme: les deux images doivent avoir la meme intensites (relation lineaire)

## Afficher la Métrique





## Métrique: Cross-Corrélation

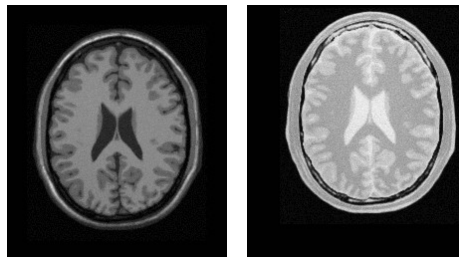
- Convolution sans inverse le signal

$$\frac{1}{n-1} \sum_{x,y} \frac{(f(x,y) - \bar{f})(t(x,y) - \bar{t})}{\sigma_f \sigma_t}$$

- $\bar{f}$  = moyenne de f
- $\sigma_f$  = écart type de f
- Relation affine entre les intensités des deux images

## Métrique: Information Mutuelle

- Issue de la théorie de l'information
- Relation statistique entre les intensités des deux images
- Densité conjointe de probabilité des niveaux de gris
- Calcul d'un histogramme conjoint
- Mesure d'entropie





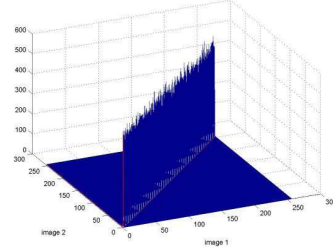
## Histogramme Conjoint

nombre de fois qu'une combinaison de niveau de gris est rencontré dans les deux images

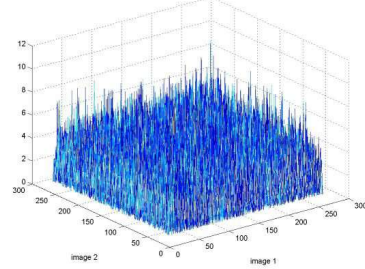
niveau de gris sur image 2  
 $\in [0,255]$

niveau de gris sur image 1  
 $\in [0,255]$

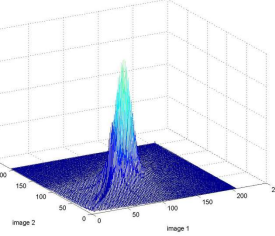
histogramme conjoint de deux images identiques



histogramme conjoint avec bruit blanc

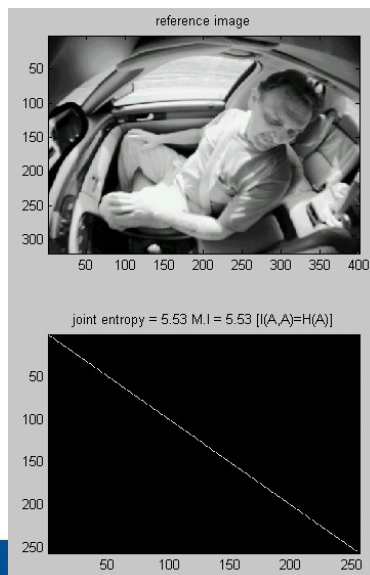


histogramme conjoint de deux images proches



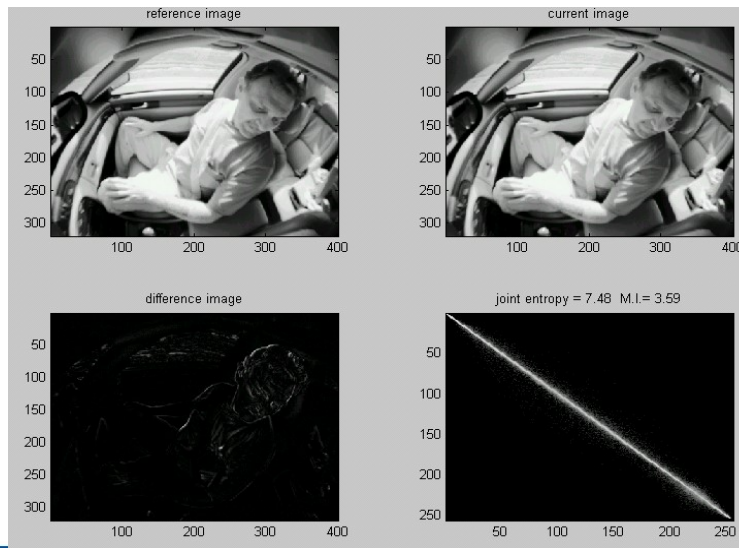
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## Métrique: Information Mutuelle



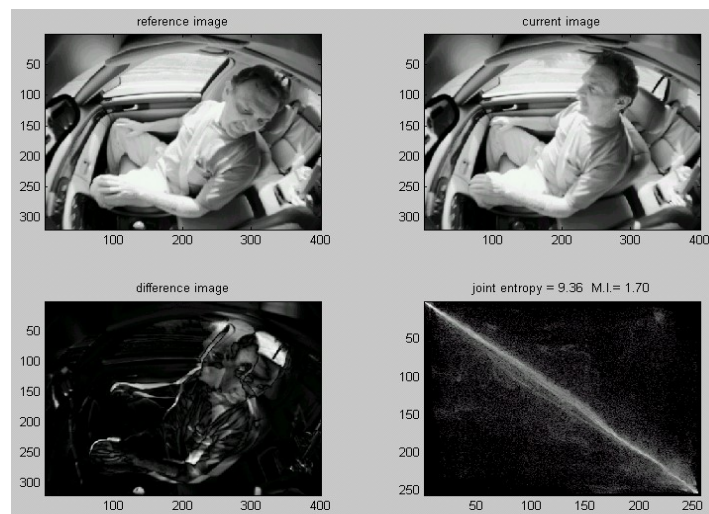
32

## Métrique: Information Mutuelle



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## Métrique: Information Mutuelle



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## Métrique: Information Mutuelle

- Soit  $g(x,y)$  la valeur de l'histogramme conjoint au point  $[x,y]$ .

$$p_{1,2}(x,y) = \frac{g(x,y)}{\sum_{a,b} g(a,b)}$$

$$p_1(x) = \sum_b p_{1,2}(x,b)$$

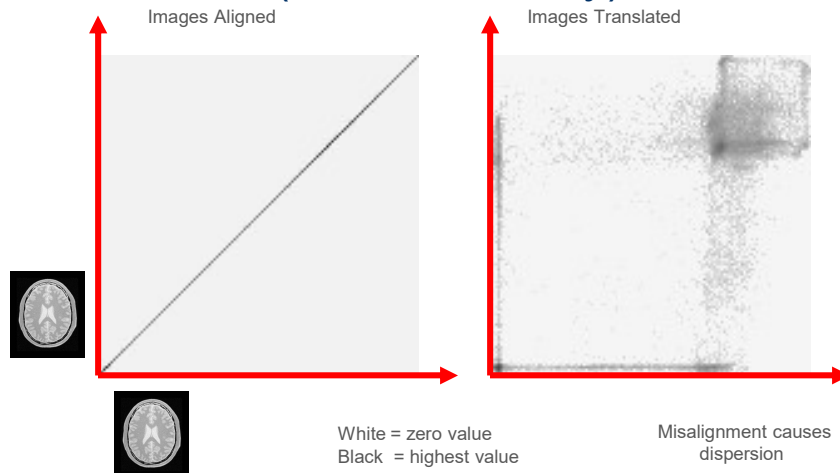
$$p_2(y) = \sum_a p_{1,2}(a,y)$$

$$MI = \sum_{a,b} p_{1,2}(a,b) \log_2 \frac{p_{1,2}(a,b)}{p_1(a) \cdot p_2(b)}$$

## Métrique: Information Mutuelle

- $\sum_{a,b} g(a,b)$  = nombre de point utilisés pour créer l'histogramme conjoint.
- $p_{1,2}(x,y)$  = histogramme conjoint normalisé. C'est aussi une distribution de probabilité. Probabilité qu'un point pris au hasard dans l'image soit la combinaison de niveau de gris  $x$  sur  $I_1$  et  $y$  sur  $I_2$ .
- $p_1(x)$  = distribution de probabilité. Pour un  $x$  donne = probabilité de que l'on trouve un point de niveau de gris  $x$  sur l'image 1.

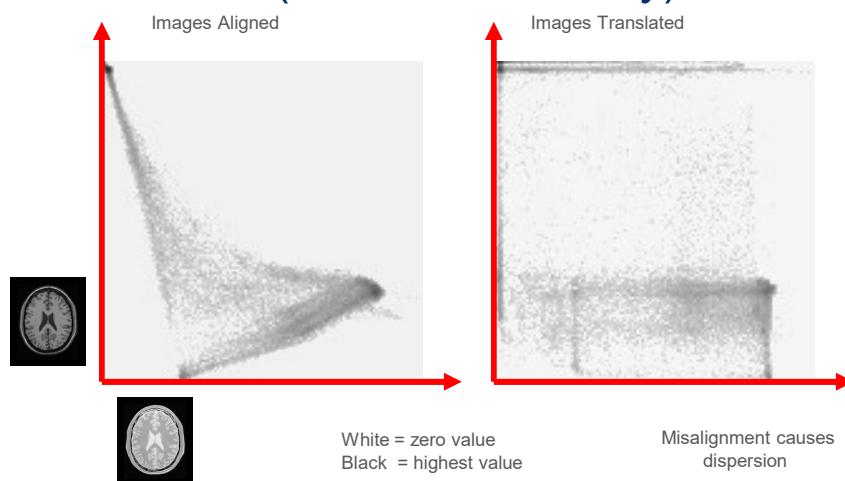
## Mutual Information (Same Modality)



Insight/Examples/Registration/ImageRegistrationHistogramPlotter.cxx

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## Mutual Information (Different Modality)



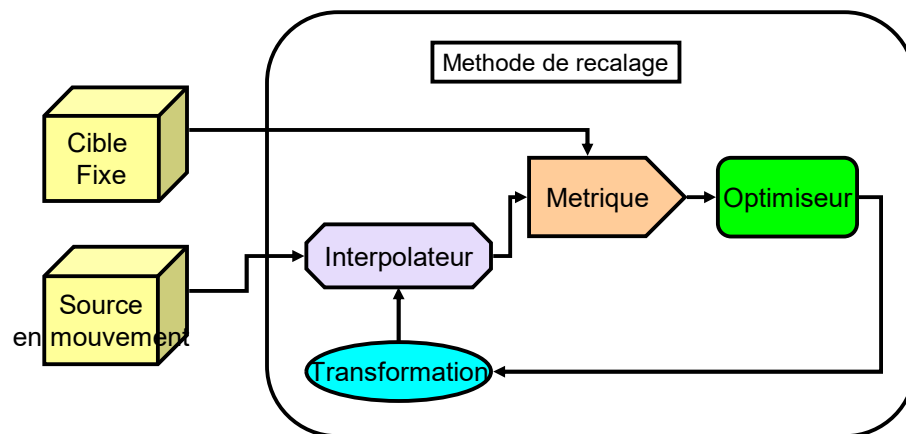
Insight/Examples/Registration/ImageRegistrationHistogramPlotter.cxx

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## Composants du recalage

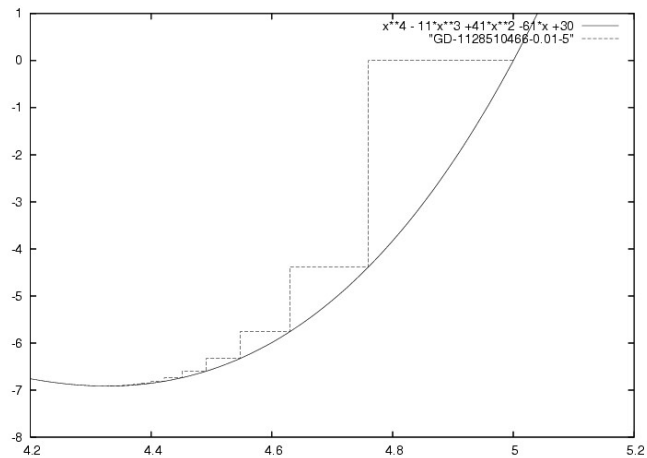
- Transformation
- Métrique
- **Optimiseur**
- Interpolateur

## Composants du recalage



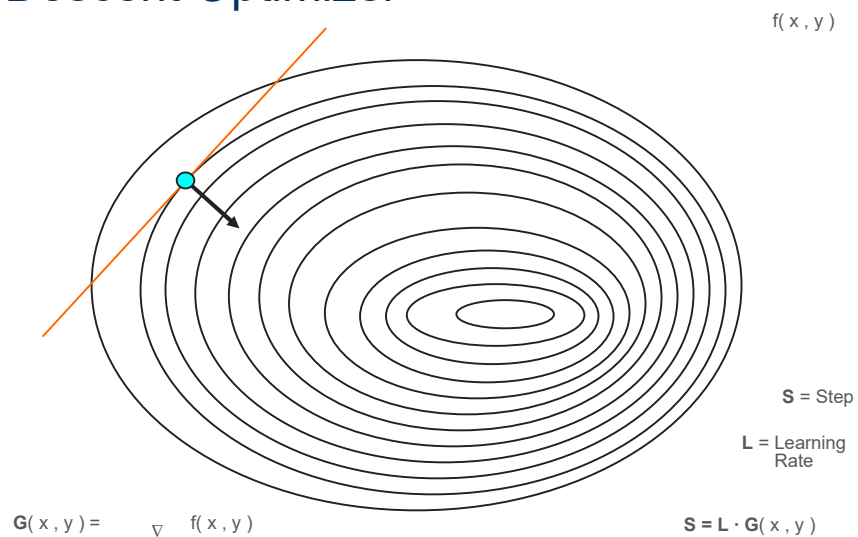
## Optimiseur: Descente de gradient

- Fonction C1
- $x_{i+1} = x_i - L E'(x_i)$
- $L = \text{"pas d'apprentissage"}$



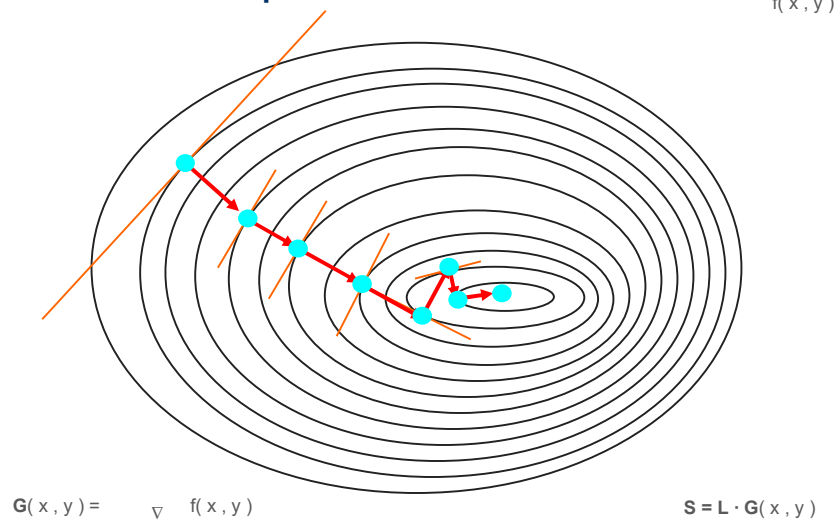
41

## Gradient Descent Optimizer



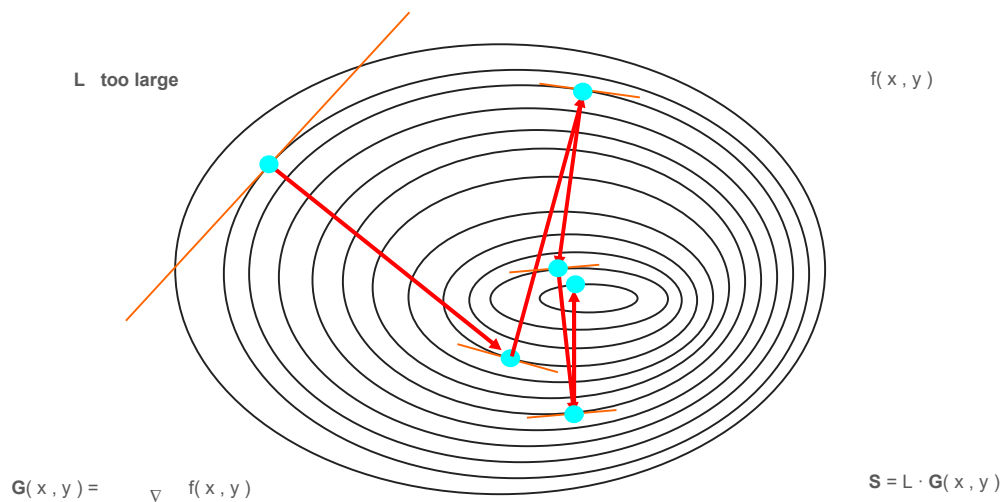
42

## Gradient Descent Optimizer



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## Gradient Descent Optimizer

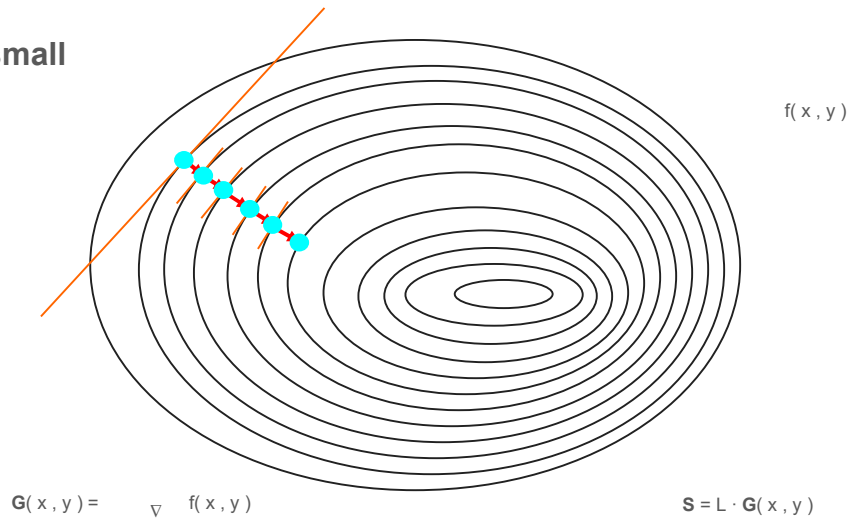


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## Gradient Descent Optimizer

**L too small**



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## Autres optimiseurs

- Une ou plusieurs valeurs à optimiser
- Dépend de la métrique
- Gradient Conjugué
- Algorithmes génétiques:
  - 1+1 evolutionary
  - Amoeba
- Powell
- LBFGS
- Levenberg Marquardt

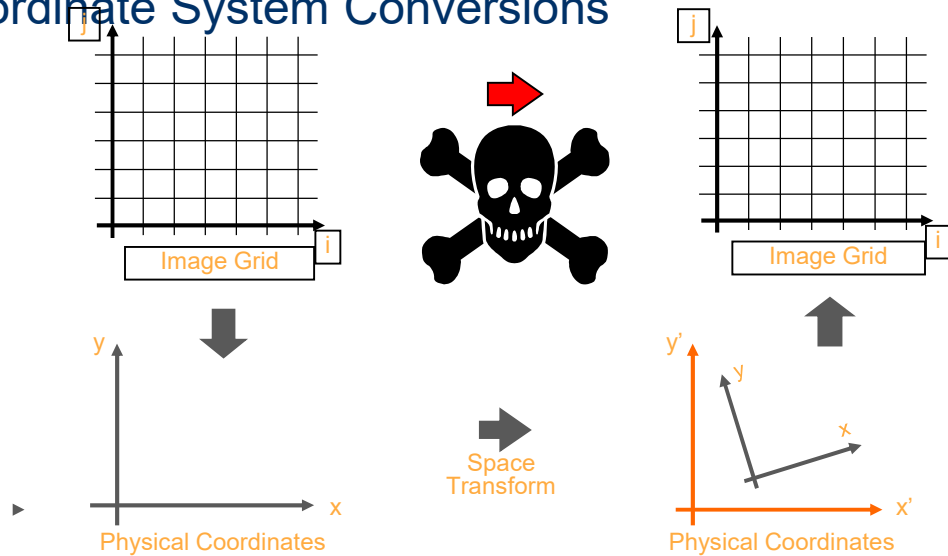
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## Composants du recalage

- Transformation
- Métrique
- Optimiseur
- Interpolateur

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## Coordinate System Conversions



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## Things I will not do...

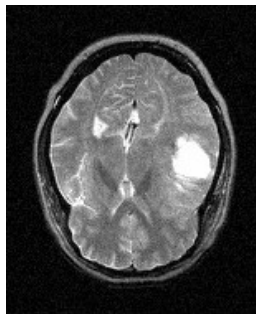
*I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pixel space*



## Quiz #1

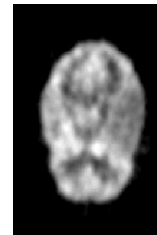
Images from the same patient

MRI-T2



256 x 256 pixels

PET



128 x 128 pixels

Moving Image ?

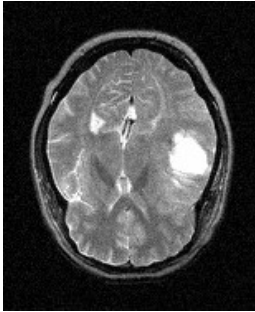
Fixed Image ?

Images provided as part of the project: "Retrospective Image Registration Evaluation",  
NIH, Project No. 8R01EB002124-03, Principal Investigator, J. Michael Fitzpatrick, Vanderbilt University, Nashville, TN.

## Quiz #2

Images from the same patient

MRI-T2




256 x 256 pixels

Scaling Transform

What scale factor ?

- a) 2.0
- b) 1.0
- c) 0.5

PET



128 x 128 pixels

Images provided as part of the project: "Retrospective Image Registration Evaluation",  
NIH, Project No. 8R01EB002124-03, Principal Investigator, J. Michael Fitzpatrick, Vanderbilt University, Nashville, TN.

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## Things I will not do...

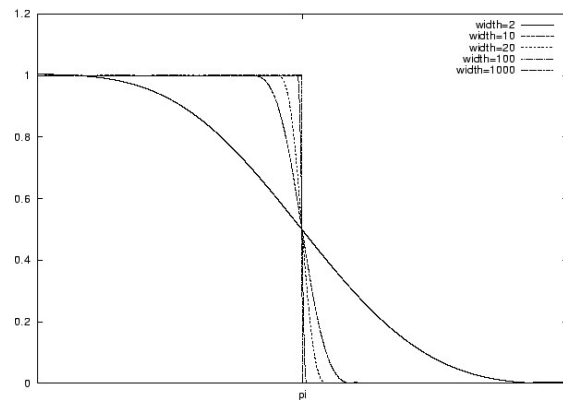
*I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pixel space  
I will not register images in pix*



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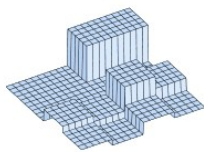
## Interpolation

- Plus proche voisin (nearest neighbor)
- Linéaire
- Window Sinc
- BSpline
- ...

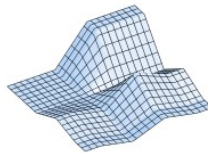


## Interpolation

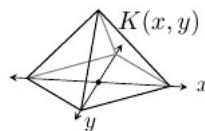
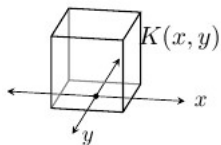
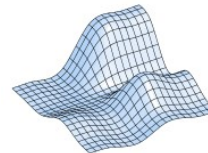
Nearest Neighbor



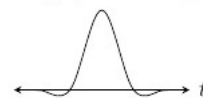
Bilinear



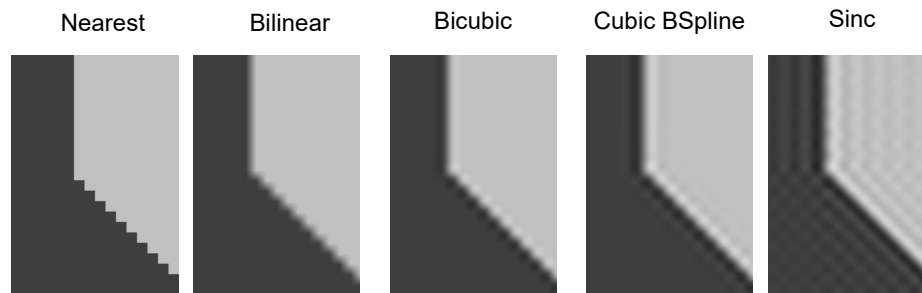
Bicubic



$K_1(t)$  ( $\alpha = -0.5$ )

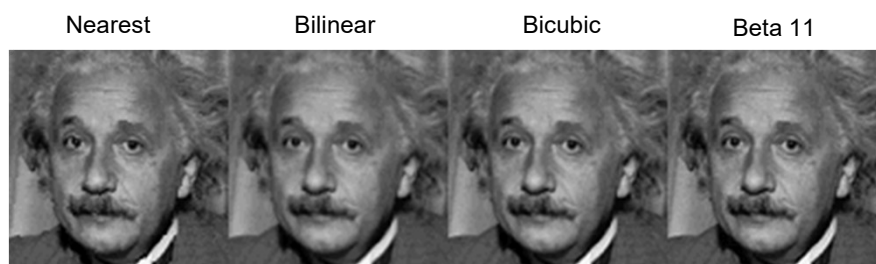


## Interpolation



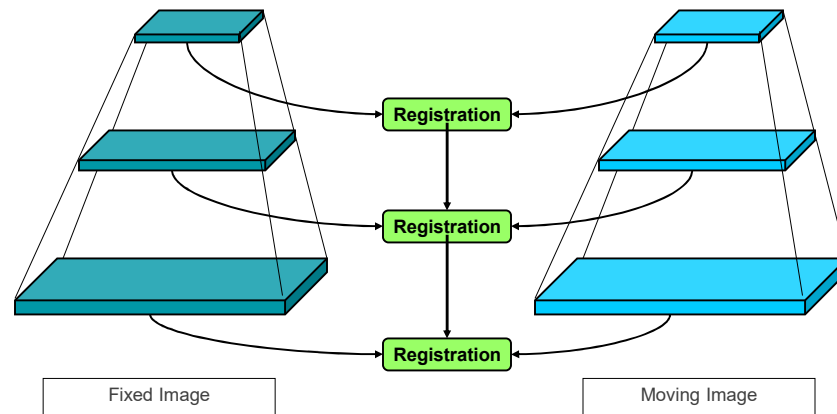
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## Interpolation: rotation



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## Recalage Multi-résolution



## Applications Imagerie Médicale

- Recalage model-image
- Recalage monomodale
  - Intra patient
  - Inter patient
- Recalage multimodale
  - Différentes modalités



## TP

- Python
- Insight Toolkit
  - Transformations: Code/Common
  - Optimiseurs: Code/Numerics
  - Métriques: Code/Algorithms
  - Interpolateurs: Code/Common

# Recalage

Module Image – CPE Lyon

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