Image segmentation with a statistical shape prior

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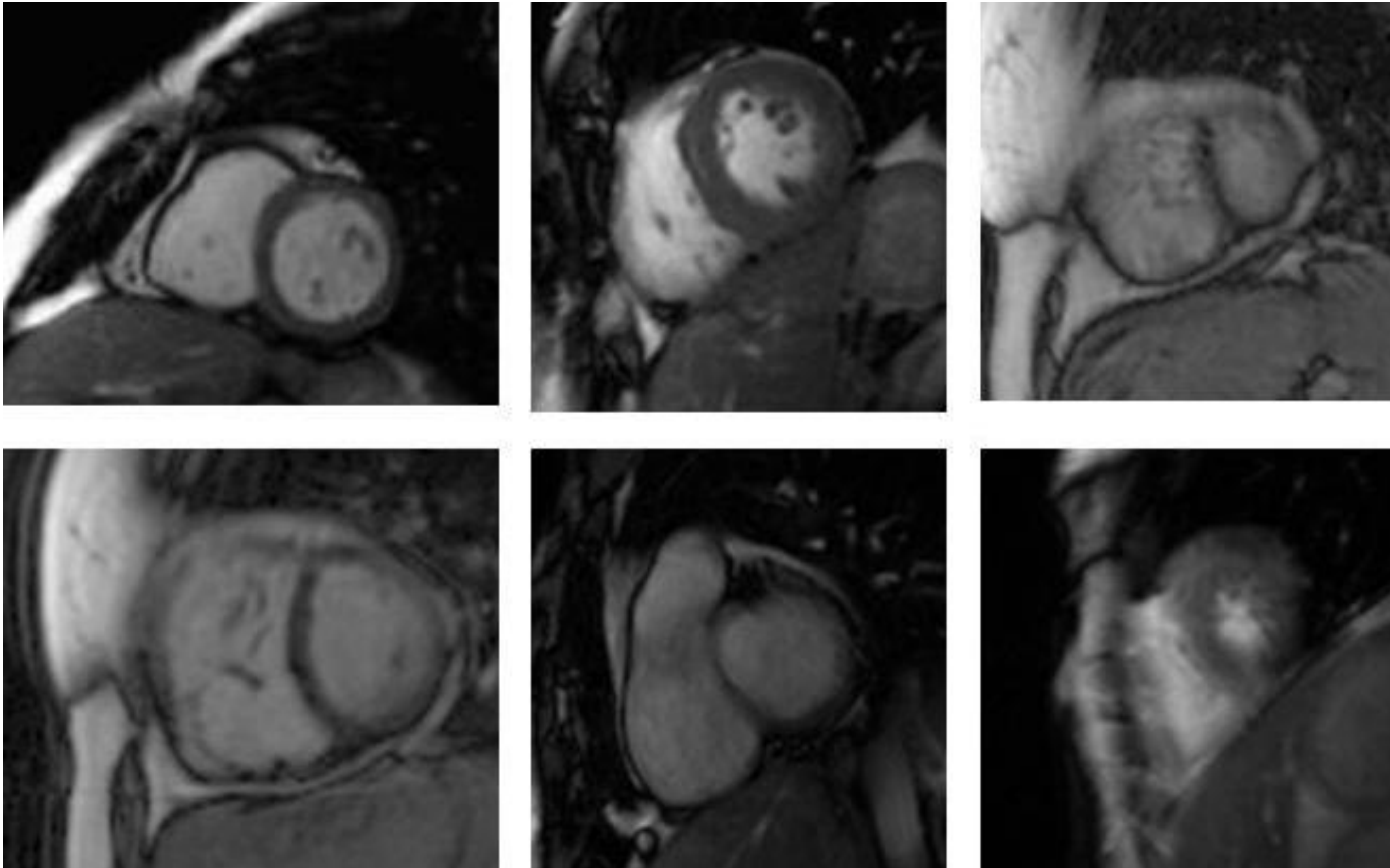
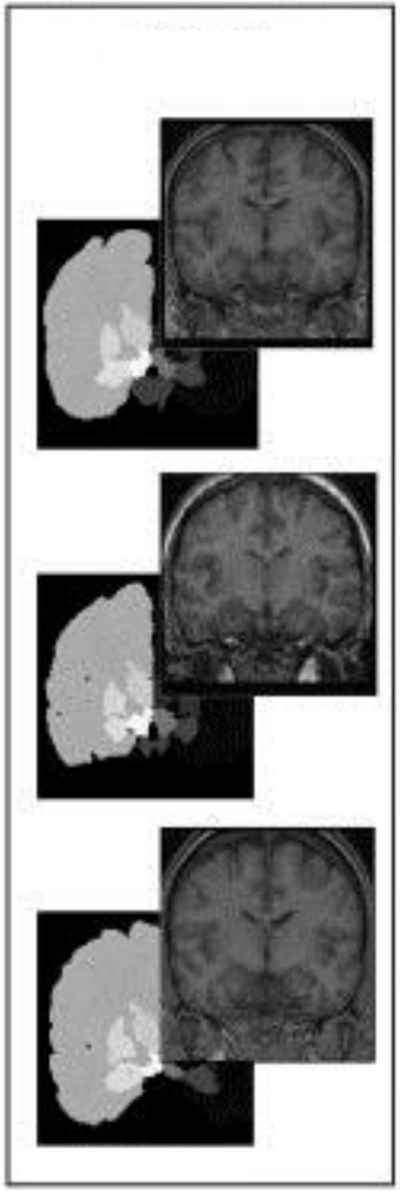
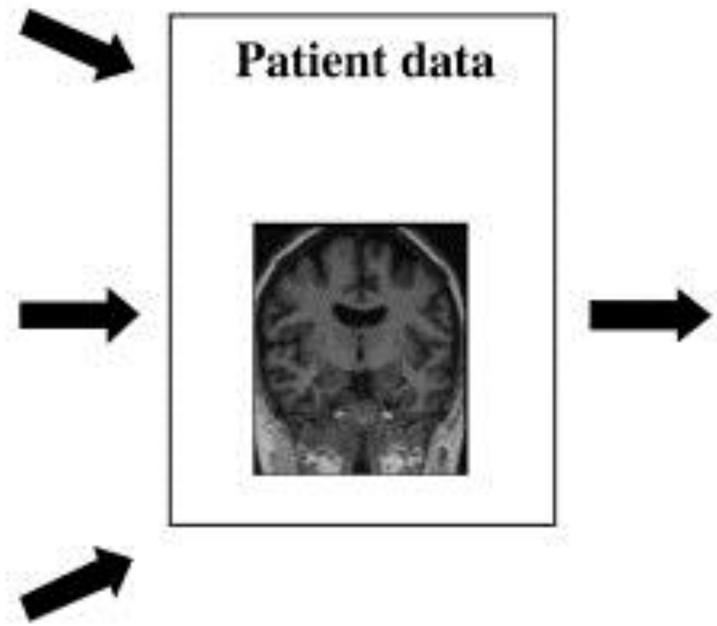
Shape prior based image segmentation



Prior information based segmentation



Our assumption: *n* atlases or label maps



Segmentation
of
patient data
?

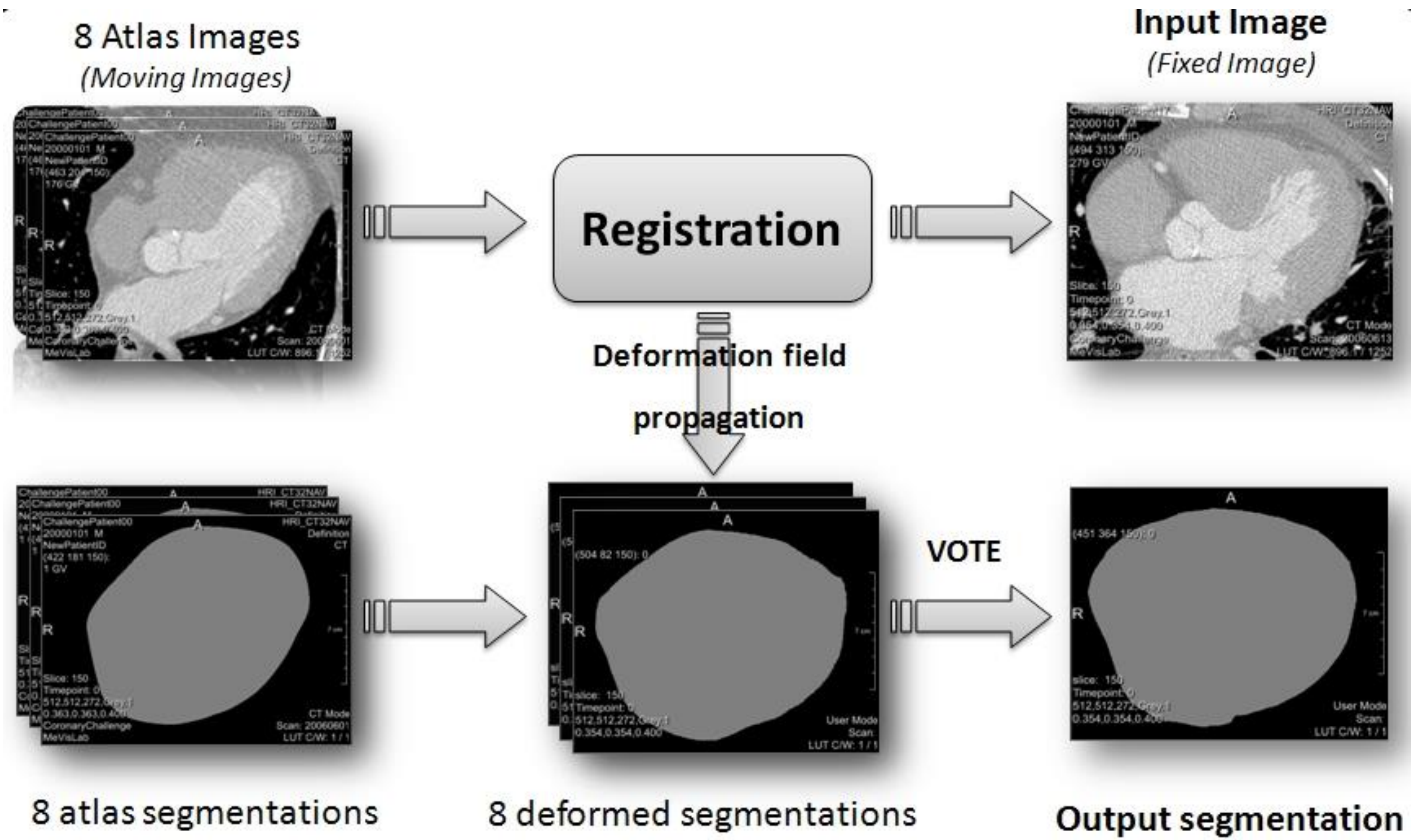
→Atlas registration based approaches
→Statistical shape prior based approaches

Lotjönen’10

Outline

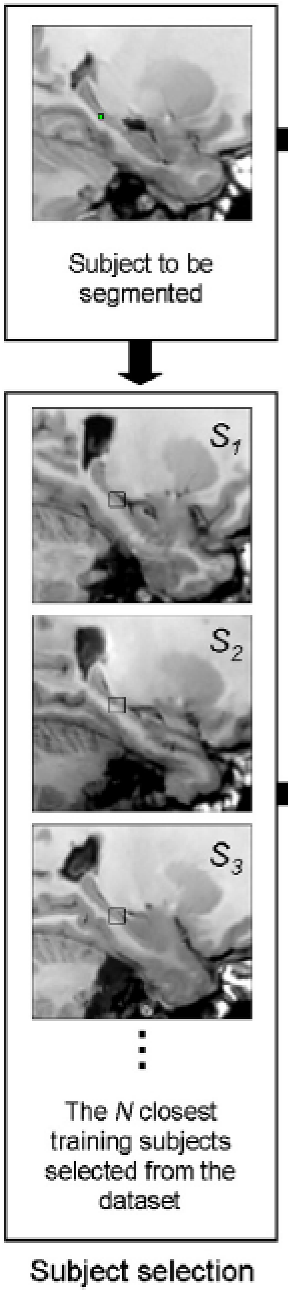
- Related works in prior information segmentation
  - Atlas based approaches
  - Statistical shape prior based approaches
- Manifold learning for shape set modelling
- ML-based shape prior segmentation framework
- A few results on cardiac MRI

Multi-atlas registration for image segmentation



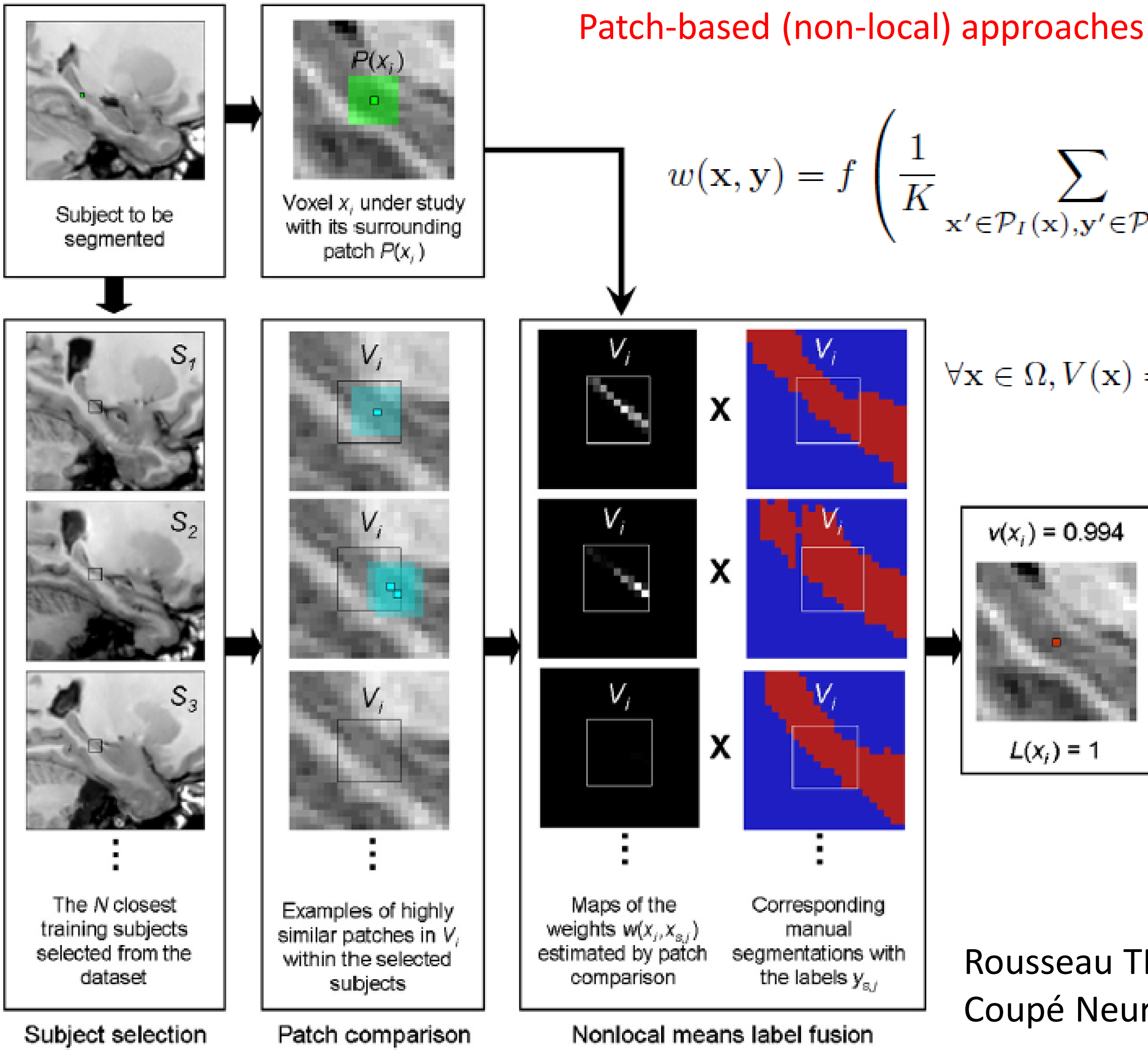
Kirisli'10

Multi-atlas: recent developments



Multi-atlas: recent developments

Patch-based (non-local) approaches



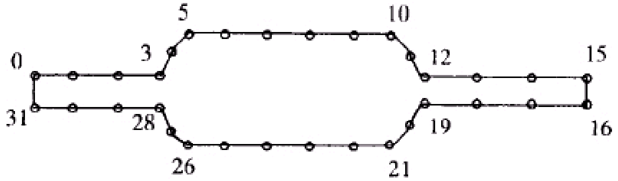
$$w(\mathbf{x},\mathbf{y}) = f\left(\frac{1}{K}\sum_{\mathbf{x}'\in\mathcal{P}_I(\mathbf{x}),\mathbf{y}'\in\mathcal{P}_{\mathcal{I}_i}(\mathbf{y})}(I(\mathbf{x}')-\mathcal{I}_i(\mathbf{y}'))^2\right)$$

$$\forall \mathbf{x}\in\Omega, V(\mathbf{x}) = \frac{\sum_{\mathbf{y}\in\mathcal{N}(\mathbf{x})} w(\mathbf{x},\mathbf{y})\mathcal{L}(\mathbf{y})}{\sum_{\mathbf{y}\in\mathcal{N}(\mathbf{x})} w(\mathbf{x},\mathbf{y})}$$

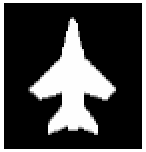
Rousseau TMI’10
Coupé NeuroImage’11

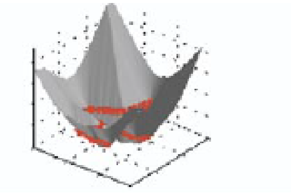
Statistical shape model for image segmentation

- **Objective:**
  - learn the possible shape deformations of an object statistically from a set of training shapes
  - restrict the contour deformation to the subspace of familiar shapes during the segmentation process
  - Active Shape Models, Cootes 1995



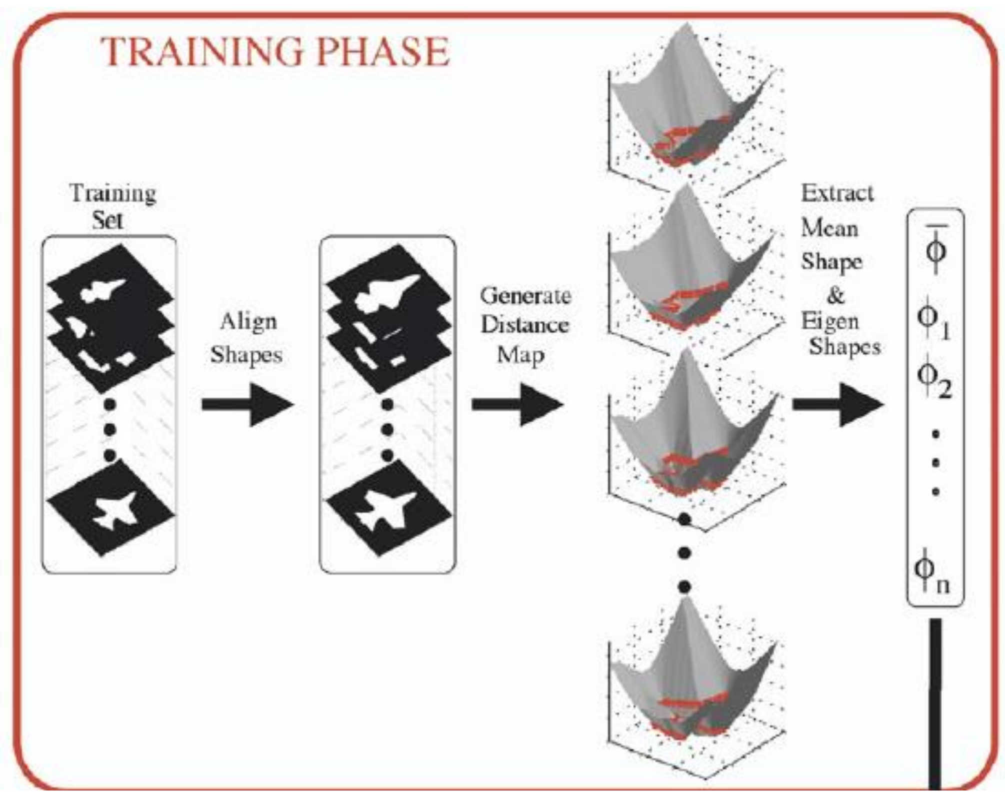
  - Leventon CVPR'00, Tsai TMI'03
    - Implicit representation





Statistical shape model for image segmentation

Example: Tsai's framework



Shapes are represented as signed distance functions

$$\mathbb{D}_\gamma = \varepsilon(x) \inf_{y \in \partial s} d(x,y) \text{ with } \varepsilon(x) \begin{cases} +1 & \text{if } x \in s, \\ -1 & \text{if } x \notin s \end{cases}$$

After rigid alignment:

$$\Phi[\mathbf{w},\mathbf{p}](x,y) = \bar{\Phi}(\tilde{x},\tilde{y}) + \sum_{i=1}^{k} w_i \Phi_i(\tilde{x},\tilde{y})$$

Mean shape

Eigenshapes

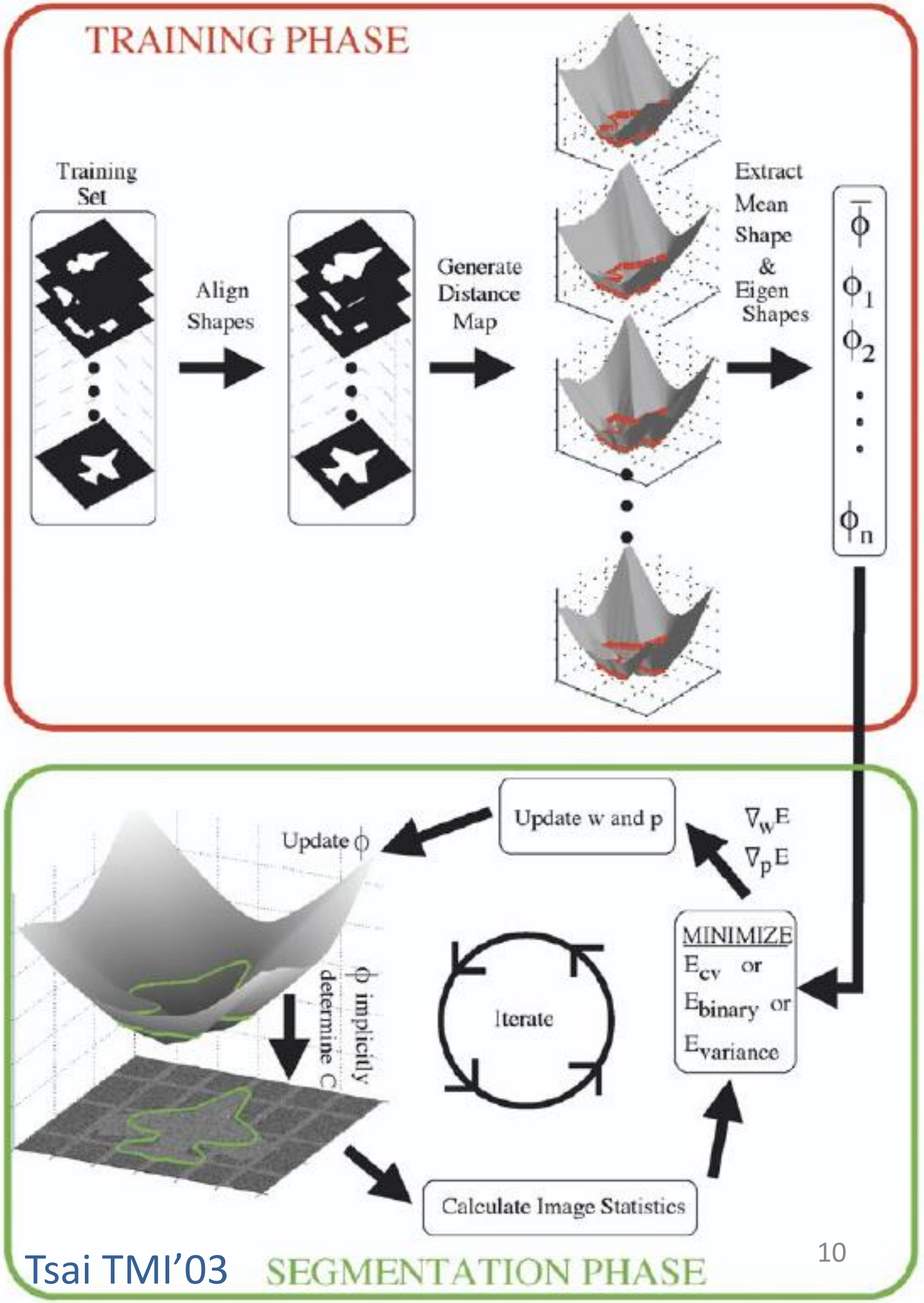
Statistical shape model for image segmentation

Example: Tsai's framework

$$\Phi[\mathbf{w},\mathbf{p}](x,y)=\bar{\Phi}(\tilde{x},\tilde{y})+\sum_{i=1}^{k} w_i\Phi_i(\tilde{x},\tilde{y})$$

$$E_{\mathrm{cv}}=\int_{R^u}(I-\mu)^2dA+\int_{R^v}(I-\nu)^2dA$$

$$\mathbf{w}^{(t+1)}=\mathbf{w}^{(t)}-\alpha_{\mathbf{w}}\nabla\mathbf{w}E$$
$$\mathbf{p}^{(t+1)}=\mathbf{p}^{(t)}-\alpha_{\mathbf{p}}\nabla\mathbf{p}E$$



Tsai TMI'03

Problems of linear shape space

- Assumes the data lie in a linear subspace
- permissible shapes are assumed to form a multivariate Gaussian distribution

Yet: real world data sets present complex deformations

- Non linear shape statistics for image segmentation
  - introduced with kPCA in Cremers, ECCV'02
  - with manifold learning techniques: Etyngier'07, Yan'13, Moolan-Ferouze'14…

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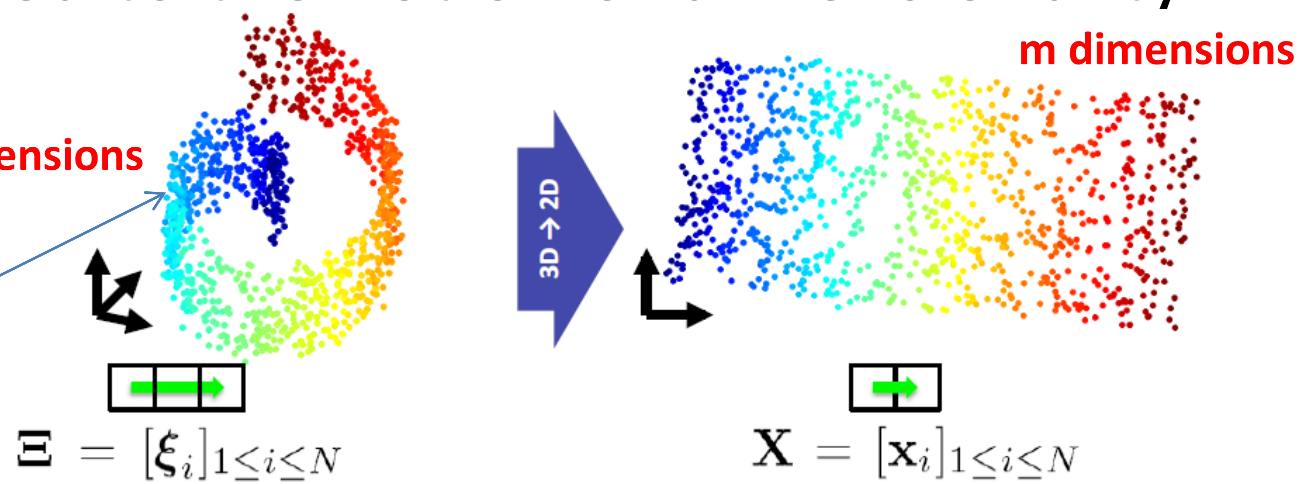
Manifold learning

- process of recovering the underlying low dimensional structure of a manifold that is embedded in a higher-dimensional space

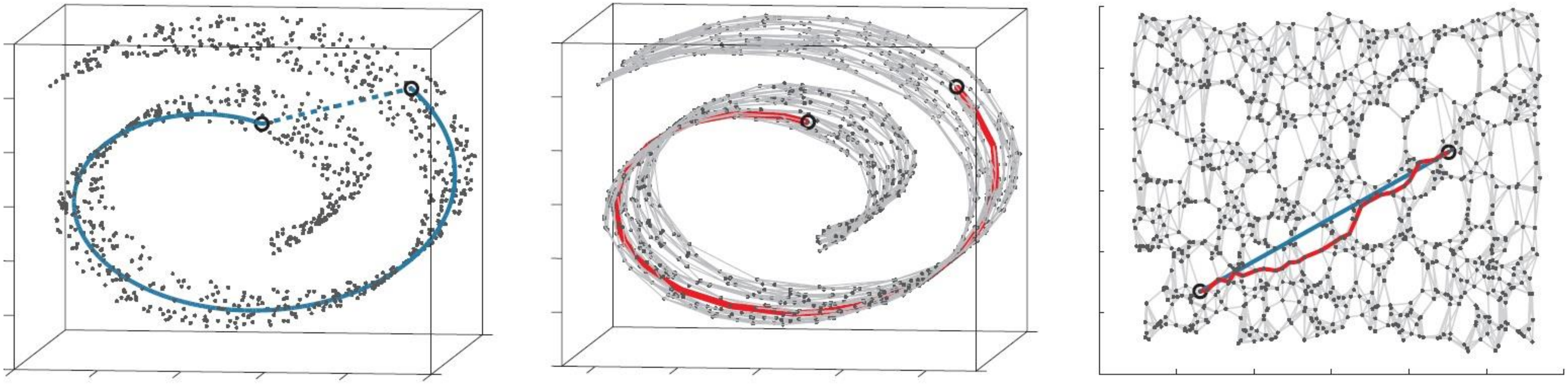
- closely related to the notion of dimensionality reduction



Source: J. Lee, UCLouvain, nov’14 seminar

Principle of spectral ML techniques

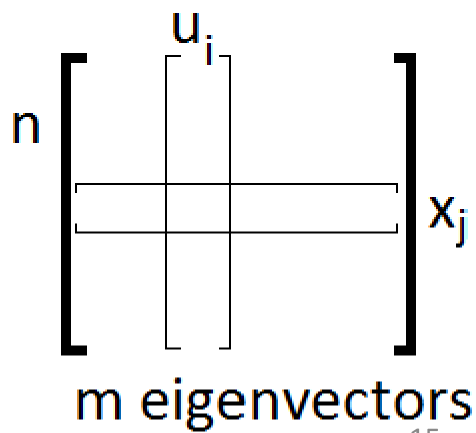
- Compute a similarity matrix M (*n x n*) between *n* points (= shapes for us) of the dataset
  - Goal: to connect points that lie within a common neighbourhood.
    - *k-nearest neighbour or ϵ - ball*



http://isomap.stanford.edu/

Principle of spectral ML techniques

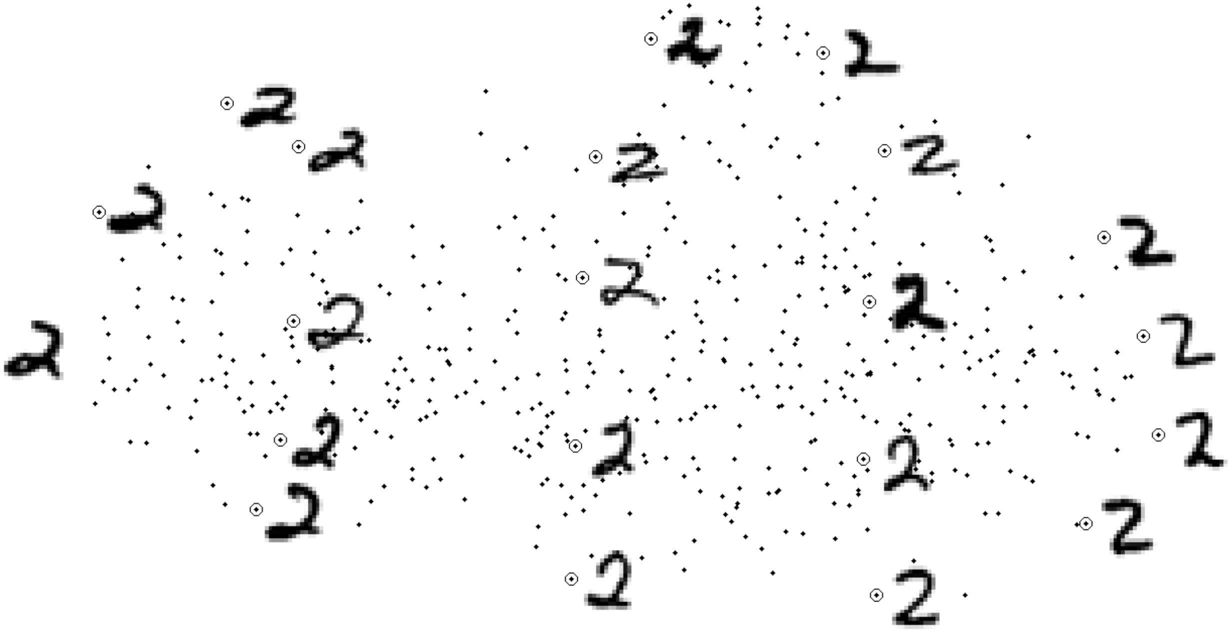
- Compute a similarity (affinity) matrix M (*n x n*)
- From M, compute a feature matrix F:
  - size n x n
  - symmetric
  - positive semi definite
- Spectral decomposition of F
- Keep the m smallest/largest eigenvectors

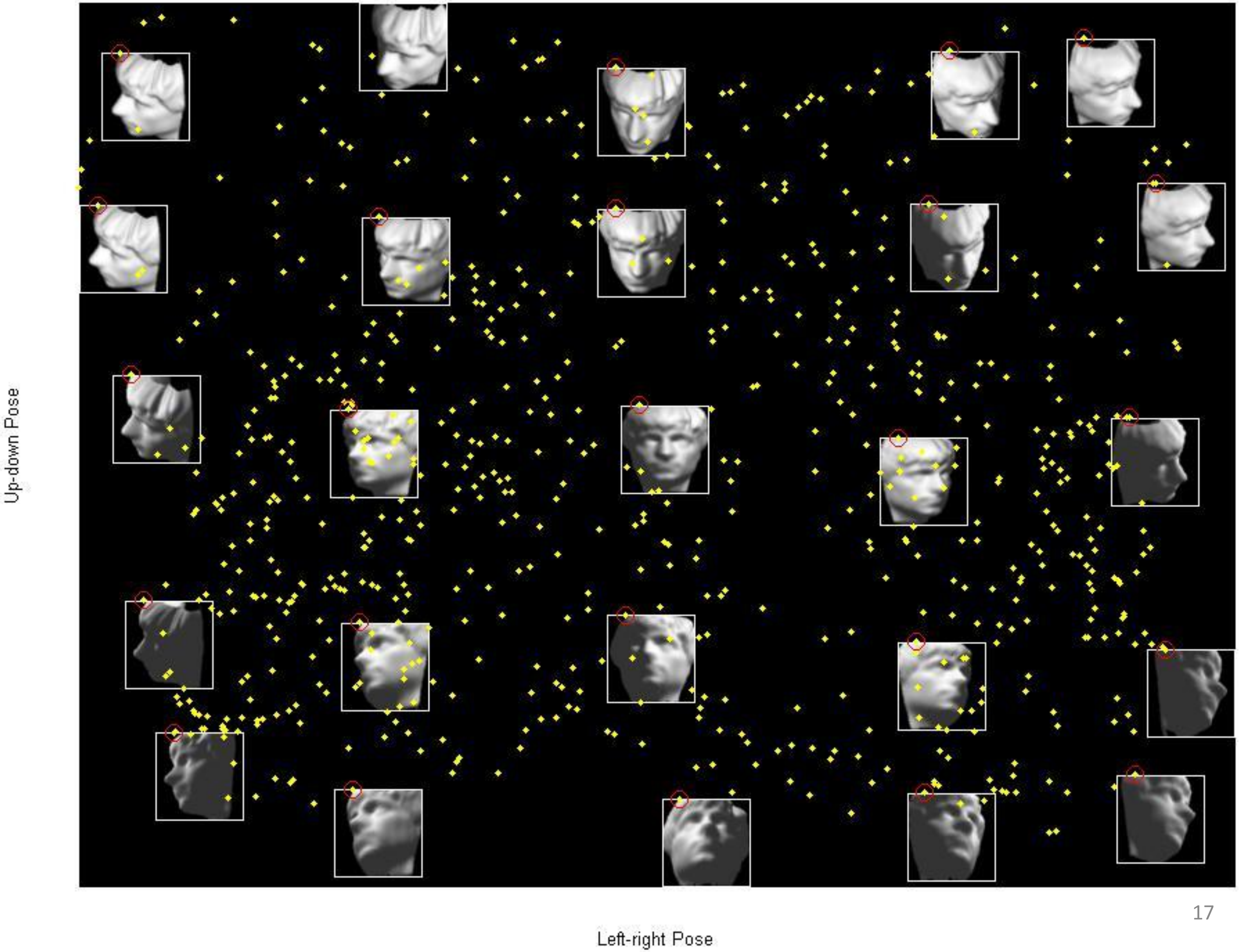


Cf Shi & Malik's Normalized cuts (PAMI'00)

An example

- Number two in MNIST database (n=500)
  - Images: 20 x 20 
  - d = 400 → m = 2




Up-down Pose
Left-right Pose

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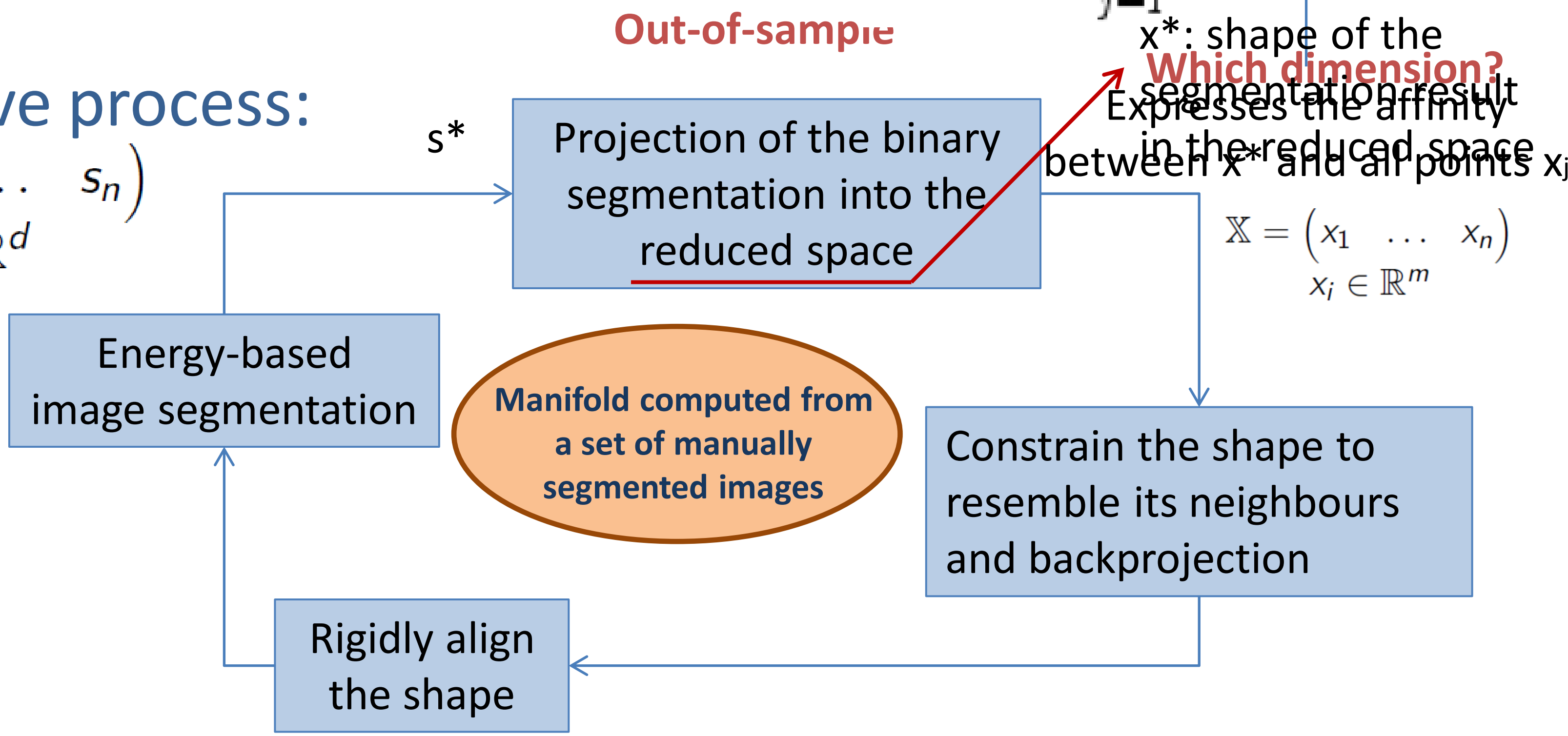
How to use an non linear shape prior for segmentation?

- Iterative process:

$$\mathbb{S} = \begin{pmatrix} s_1 & \dots & s_n \end{pmatrix}$$

$$s_i \in \mathbb{R}^d$$

$$\mathbf{x}^* = \frac{1}{\lambda_k} \sum_{j=1}^{n} \mathbf{u}_{kj} K(\mathbf{x}^*, \mathbf{x}_j)$$



Based on Etyngier ICCV'07 & Moolan-Ferouze MICCAI'14

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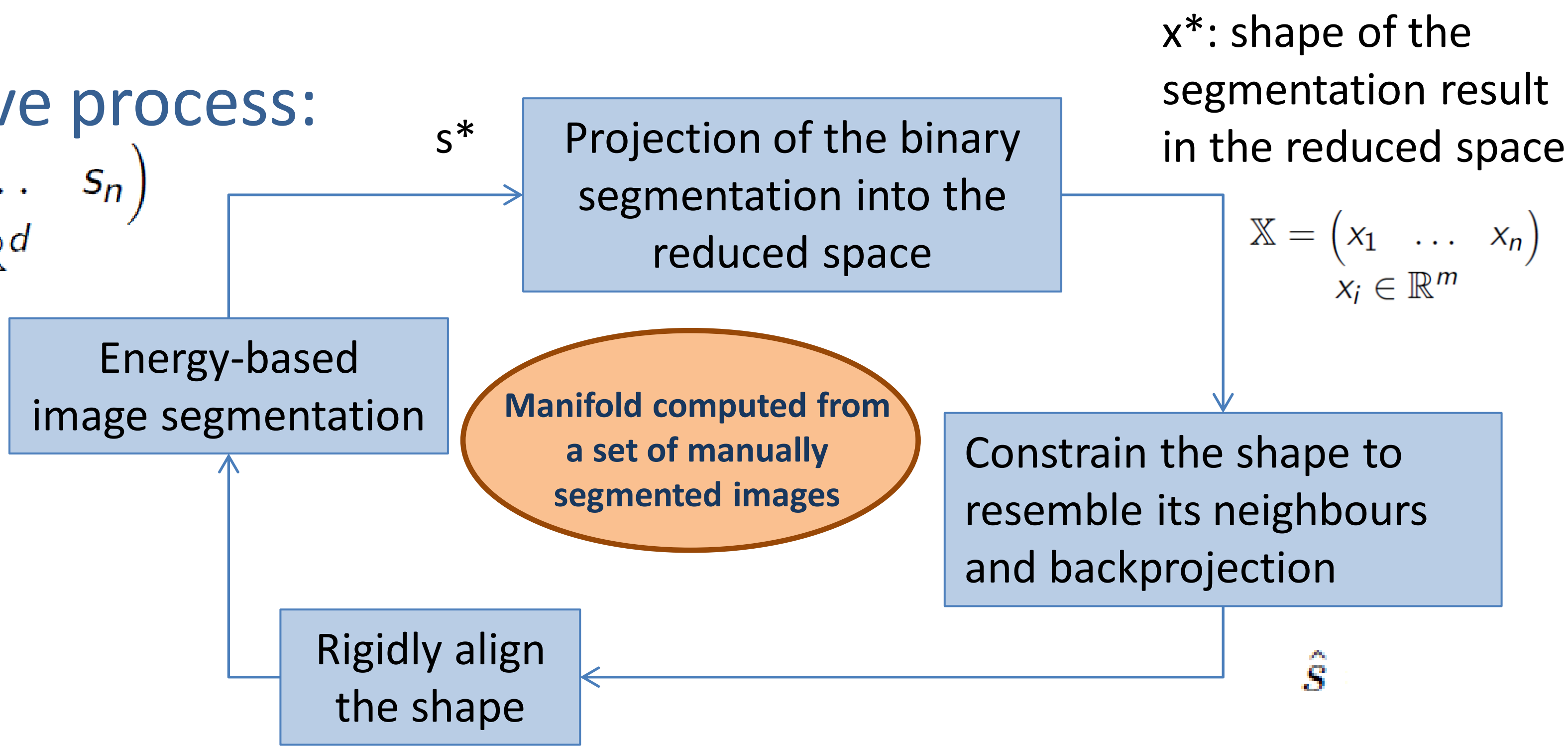


Based on Etyngier ICCV'07 & Moolan-Ferouze MICCAI'14

Constrain the shape in the embedding

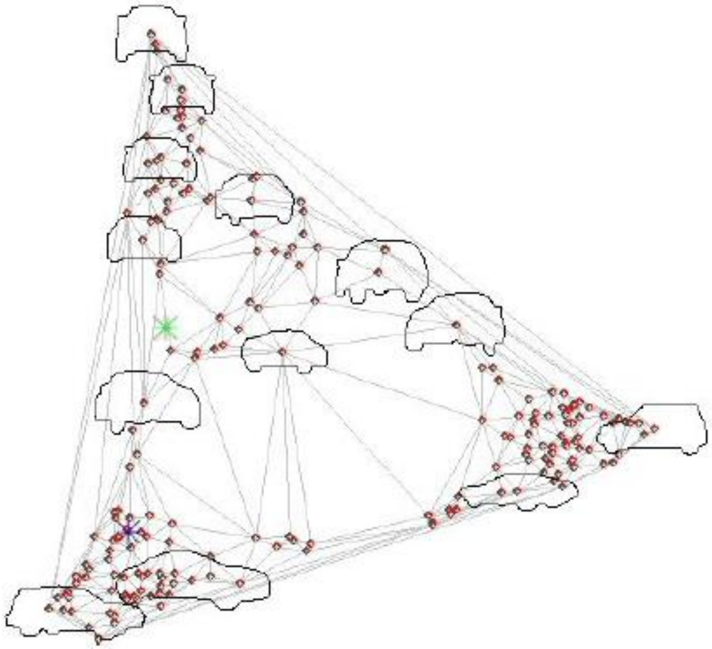
Moolan-Ferouze '14

- Find the shape nearest neighbors (NN)
- The shape $\hat{s}$ is a linear combination of its NN:

$$\hat{s} = \sum_{i=0}^{m} \theta_i s_i \quad \text{with } \sum_{i=0}^{m} \theta_i = 1 \text{ and } \theta_i \geq 0,\ \forall i = 0, \ldots, m$$

$$\hat{\theta} = \arg\min d\left(s^*, \hat{s}\right)$$

$$with \quad d\left(s^*, \hat{s}\right) = \sum \left(H(s^*) - H(\hat{s})\right)^2$$



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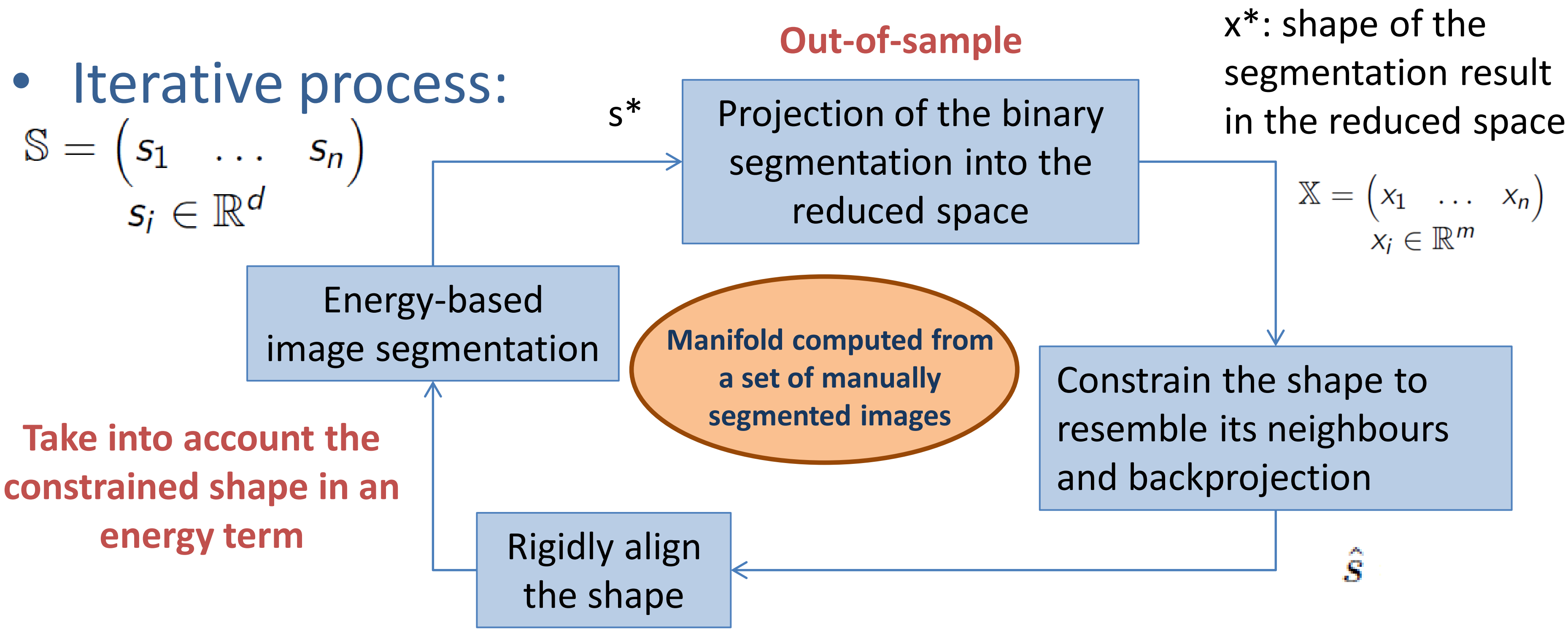

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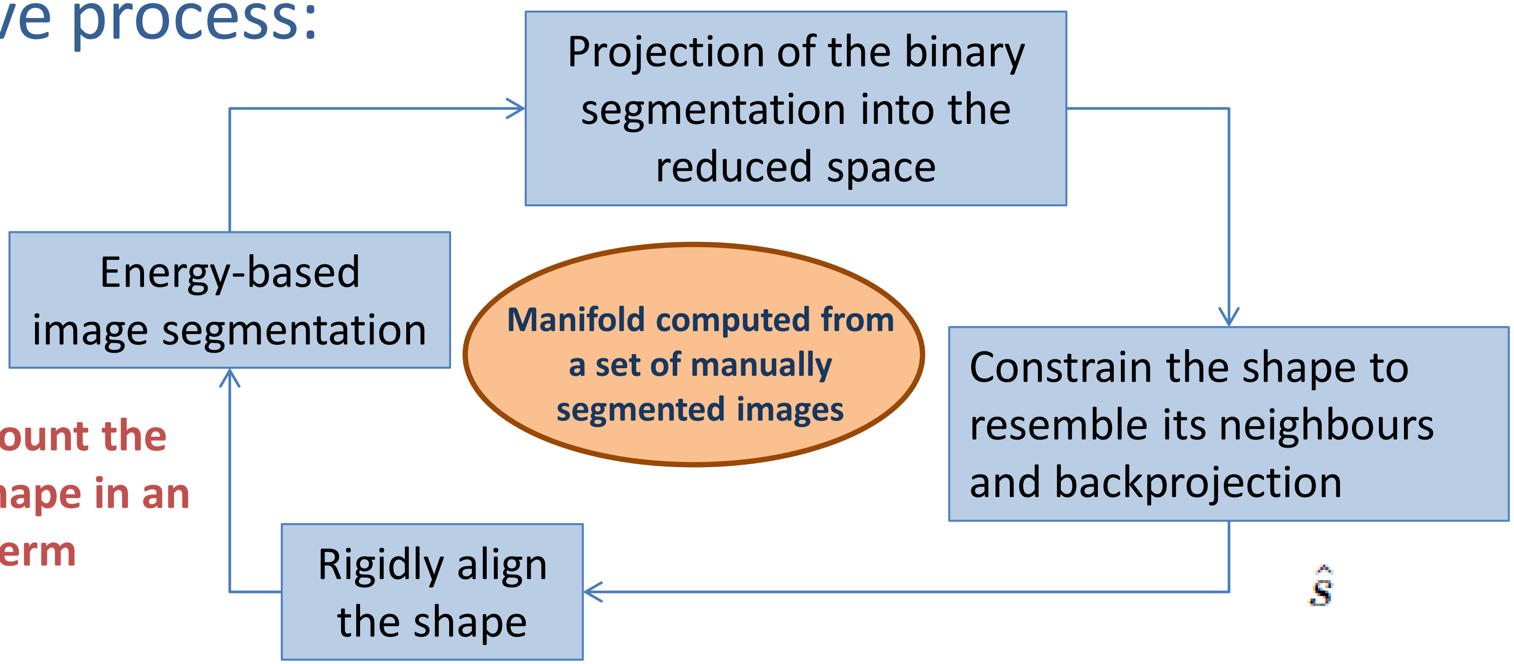
How to use an non linear shape prior for segmentation?

- Iterative process:



Take into account the constrained shape in an energy term

$$E_{total}(L) = E_{data}(L) + E_{smooth}(L) + E_{prior}(L)$$

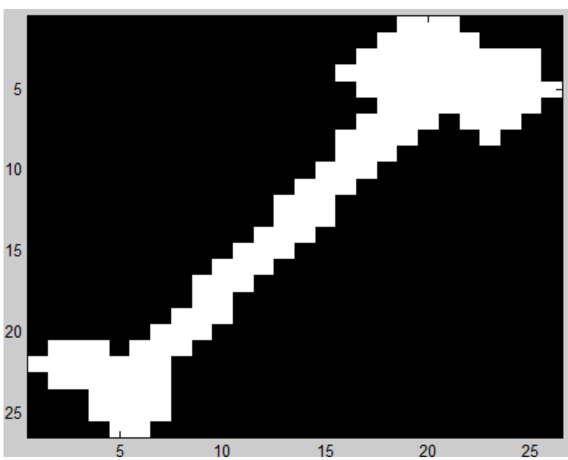
Find the labeling L such that E(L) is minimum

Shape prior energy term

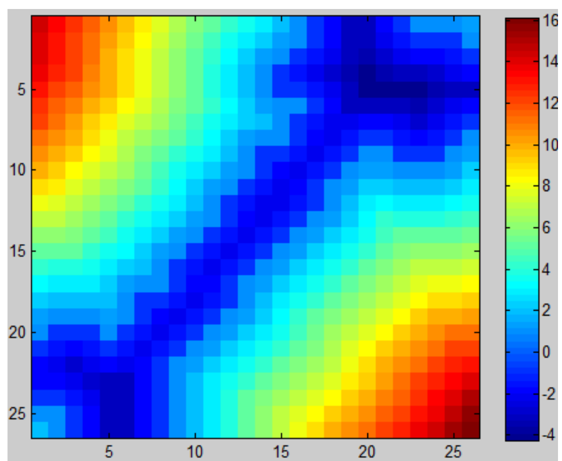
Find the labeling L such that E(L) is minimum

$E_{prior}(O)$, $E_{prior}(B)$ designed to be small for pixels likely to be labelled as object / background

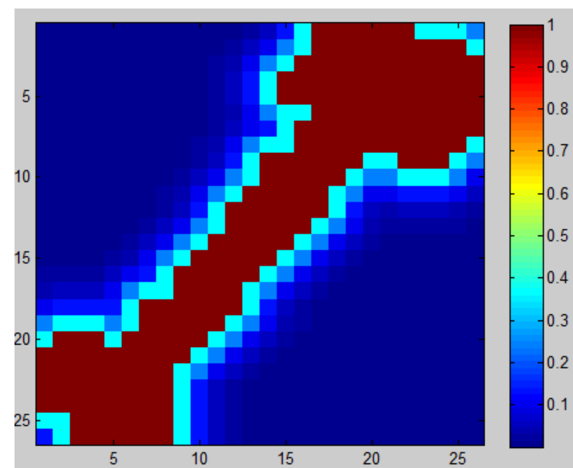
From $\hat{s}$, we define a probability atlas



Binary shape



Signed distance map



$$M(i) = \begin{cases} 1 & \text{if} \quad \hat{s}(i) \leq 0 \\ e^{-\hat{s}(i)/\gamma_{f(i)}} & \text{if} \quad \hat{s}(i) > 0 \end{cases}$$

Shape prior energy term

Find the labeling L such that E(L) is minimum

$E_{prior}(O)$ / $E_{prior}(B)$ designed to be small for pixels likely to be labelled as object / background

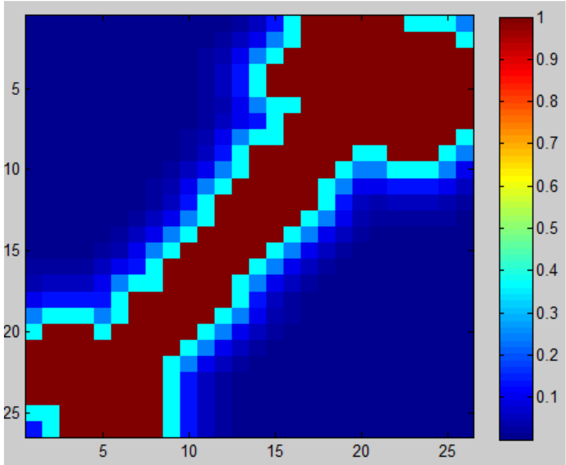
From $\hat{s}$, let's define a probability atlas

Shape prior term:

$$E_{prior}(O) = -\sum_i \log(M(i))$$

$$E_{prior}(B) = -\sum_i \log(1 - M(i))$$

Moolan-Ferouze MICCAI'14

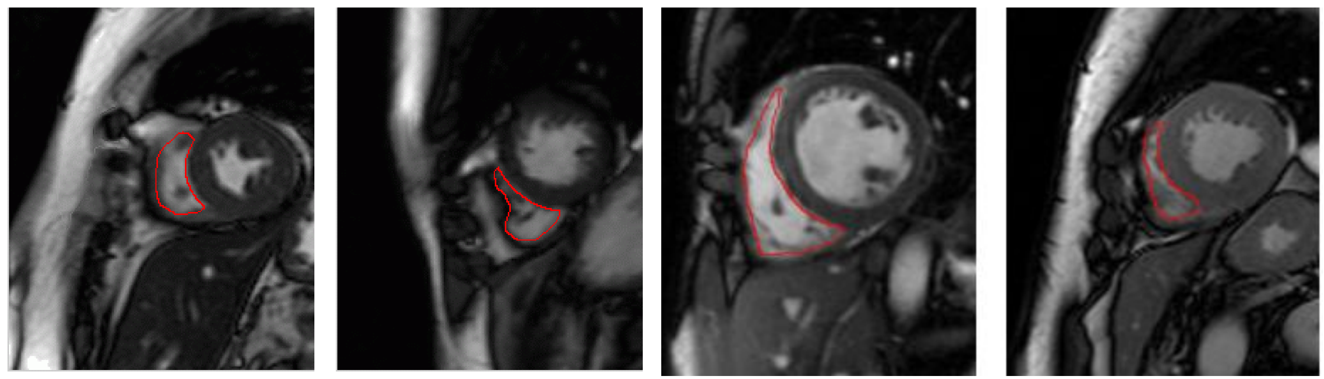


$$M(i) = \begin{cases} 1 & \text{if} \quad \hat{s}(i) \leq 0 \\ e^{-\hat{s}(i)/\gamma_{f(i)}} & \text{if} \quad \hat{s}(i) > 0 \end{cases}$$

E_{total} is minimized with the mincut – maxflow algorithm [Boykov+Kolmogorov'04]

Experimental results

- Application: segmentation of the right ventricle in cardiac MRI

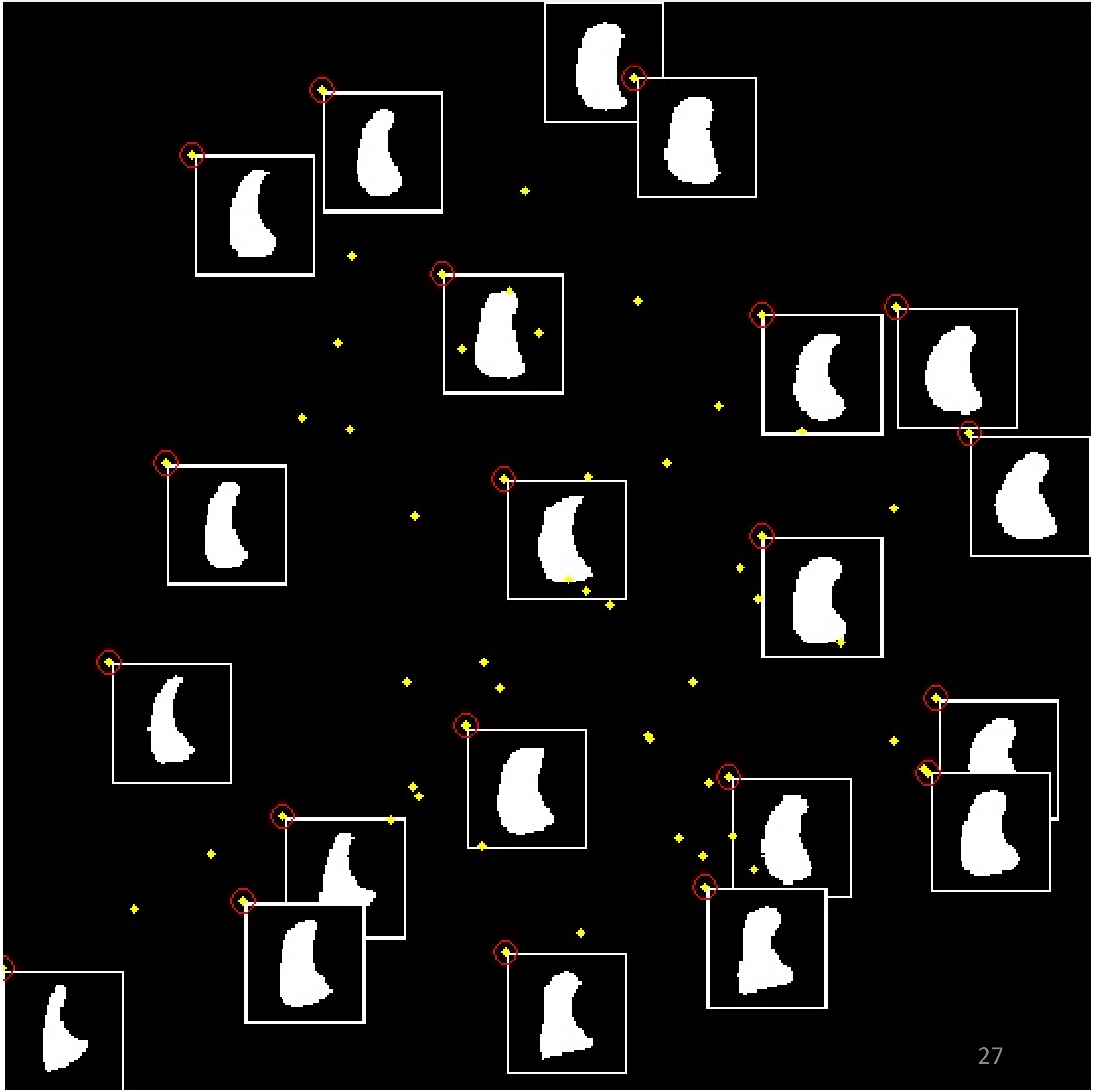


- Implementation:
  - Manifold learning: diffusion maps (Etyngier'07)
  - Graphcut based image segmentation
  - Shapes are described with signed distance maps

Experimental results

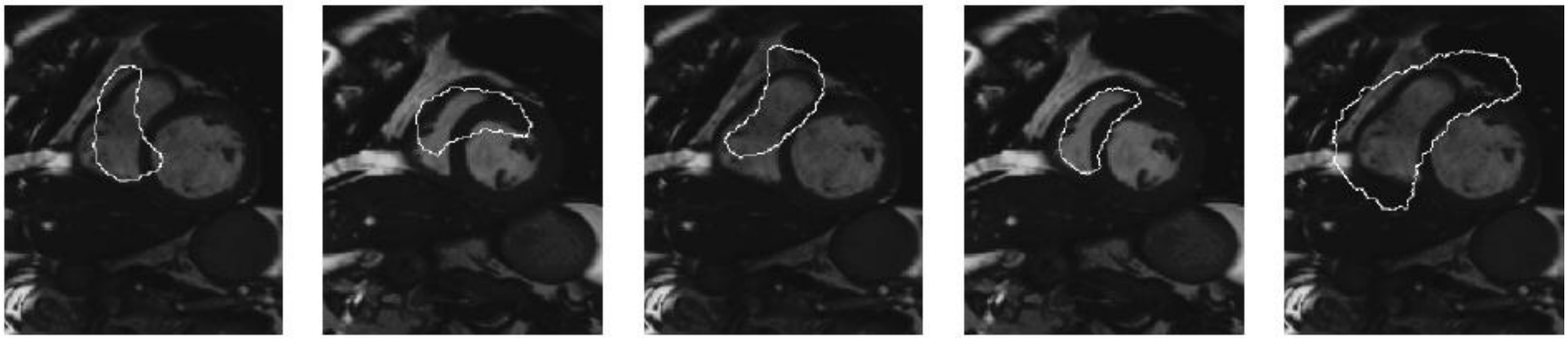
RV shape
in 2D space

(intrinsic dim≈3)

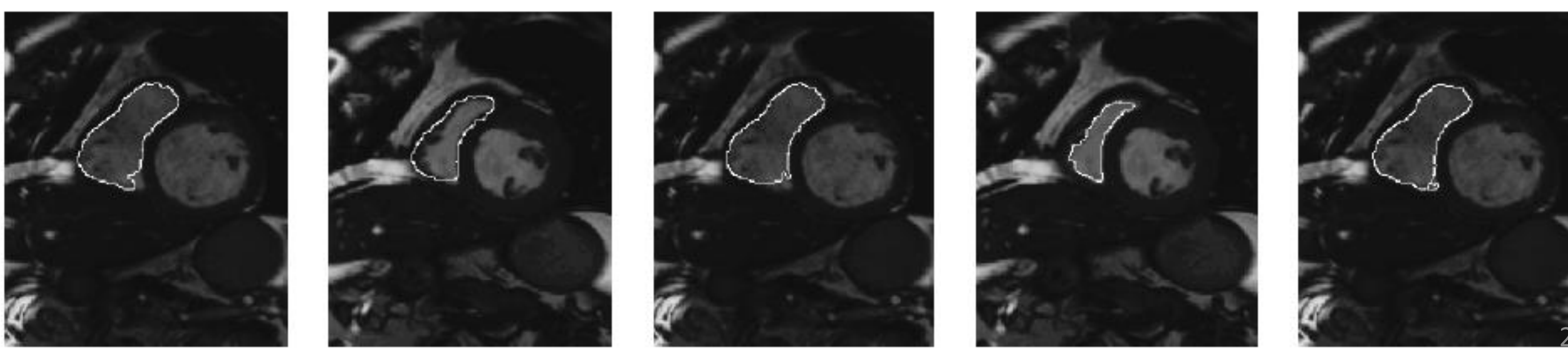


Experimental results

Initializations

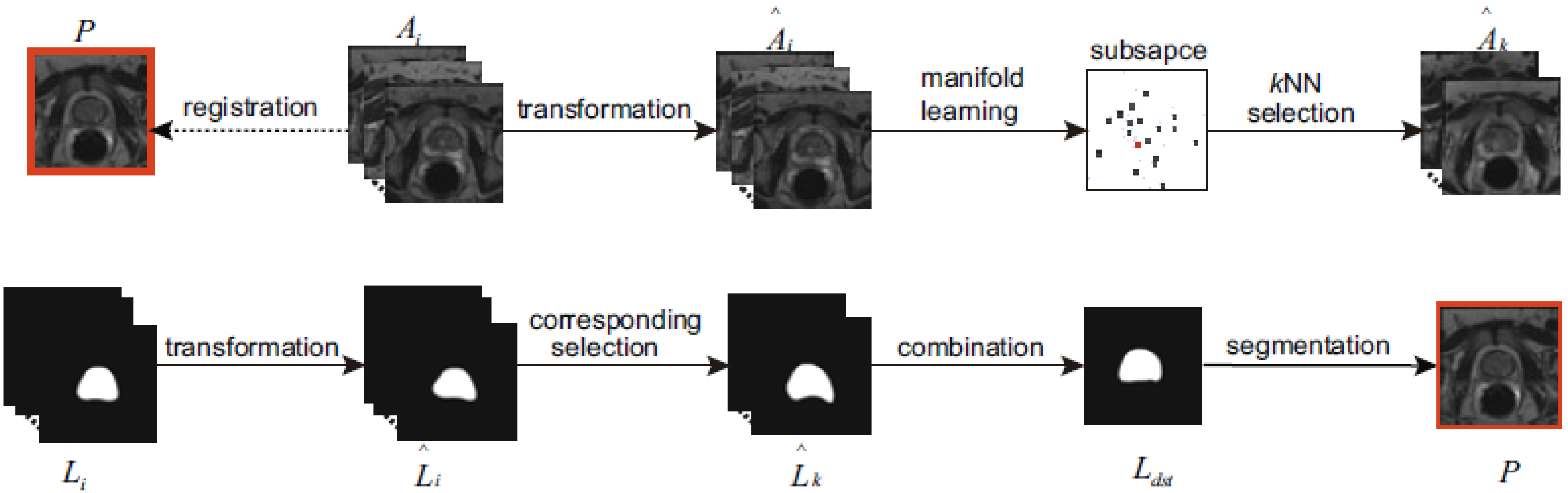


Final segmentations



Some perspectives with ML techniques

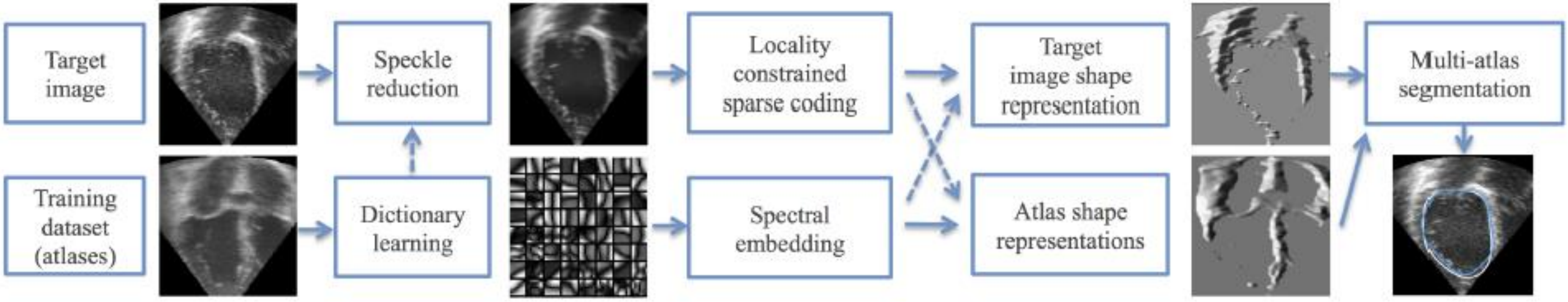
- Also investigated for atlas-based approaches
  - ML for atlas selection [Wolz NeuroImage'10, Cao MICCAI'11, Hoang-Duc PlosOne'13, Gao SPIE'14]



Cao MICCAI'11

Some perspectives with ML techniques

- Also investigated for atlas-based approaches
  - ML for atlas selection [Wolz NeuroImage'10, Cao MICCAI'11, Hoang-Duc PlosOne'13, Gao SPIE'14]
  - Patch-based approaches [Shi et al MICCAI'14, Oktay et al MICCAI'14]
    - Sparse representation and dictionary learning



Oktay et al MICCAI'14

Thank you…

- … for your attention.
- Comments? Questions?

- Caroline.Petitjean@univ-rouen.fr