Medical Image Processing for Interventional Applications

Statistical Shape Models – Part 2

Online Course – Unit 45

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Topics

Statistical Shape Models
- Shape Model Construction
- Finding Correspondences
- Appearance Models
- Search Algorithms
- Applications

Summary
- Take Home Messages
- Further Readings

Shape Model Construction

- Extract mean shape
- Extract a number of modes of variation

$\rightarrow$ Varies with the shape representation, **here**: PDMs with known correspondences

Alignment

- Shape is independent of translation, rotation and scaling.
- Normalization is required.

Generalized Procrustes alignment (GPA):

- Procrustes alignment: Minimize mean square distance between two shapes (1 base shape $+$ 1 reference shape $\Rightarrow$ 1 transformation)
- GPA: Iterate over all shapes to minimize distance to mean shape $\bar{\boldsymbol{x}}$
- Other norms than L_2 are used (e. g., $L_1, L_\infty, \ldots$).
- Tangent space is useful for improved estimation of the variation modes.
- Misalignment yields incorrect modes of variation.

Dimensionality Reduction

$\rightarrow$ Find modes of variation

Principal component analysis (PCA):

- Mean shape:

$$\bar{\boldsymbol{x}} = \frac{1}{s}\sum_{i=1}^{s} \boldsymbol{x}_i$$

- Covariance matrix:

$$S = \frac{1}{s-1}\sum_{i=1}^{s} (\boldsymbol{x}_i - \bar{\boldsymbol{x}})(\boldsymbol{x}_i - \bar{\boldsymbol{x}})^{\mathsf{T}}$$

Dimensionality Reduction

- Eigenvectors $\boldsymbol{\phi}_m$ and eigenvalues λ_m are used to identify the c-modes of variations (e. g., scree test).
- SVD of the aligned landmark matrix L delivers more stable results:

$$L = \left(\left(\boldsymbol{x}_1 - \bar{\boldsymbol{x}} \right) \ldots \left(\boldsymbol{x}_s - \bar{\boldsymbol{x}} \right) \right).$$

- Maximum number of modes is $\max\{s-1, 3K\}$.
- Robust PCA can help with outliers.

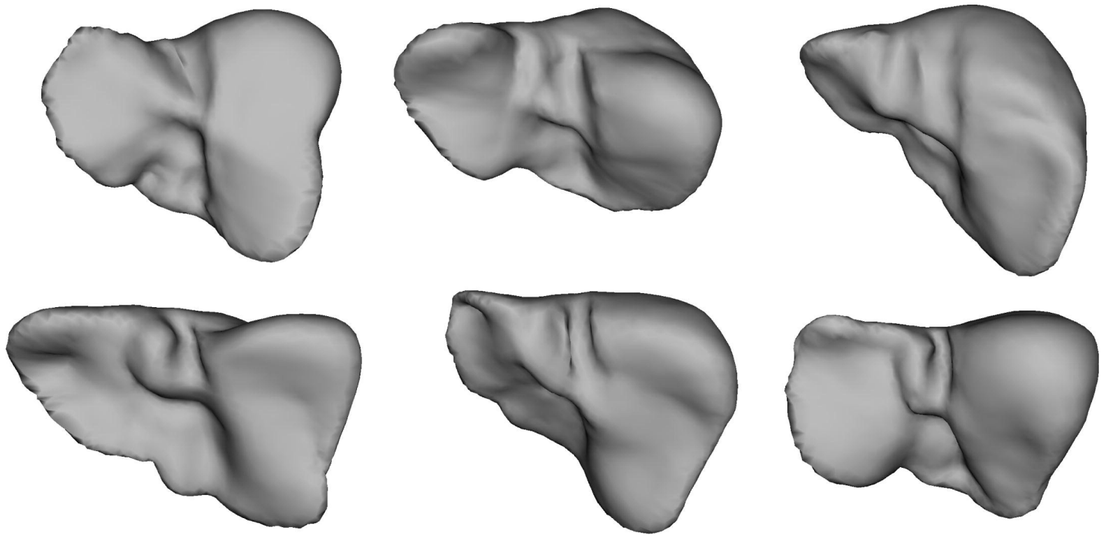

Figure 1: Variations of a shape model

Dimensionality Reduction

- Valid shapes are now expressed as linear combinations of the mean shape and its modes $\boldsymbol{\phi}_m$:

$$\boldsymbol{x} = \bar{\boldsymbol{x}} + \sum_{m=1}^{c} b_m \boldsymbol{\phi}_m, \quad b_m \in [-3\lambda_m, 3\lambda_m].$$

- Independent component analysis (ICA) can also be used, but problems such as the ordering of the components arise.

Finding Correspondences: Mesh to Mesh

- Manual landmarks $\rightarrow$ high effort/infeasible
- Automatic registration

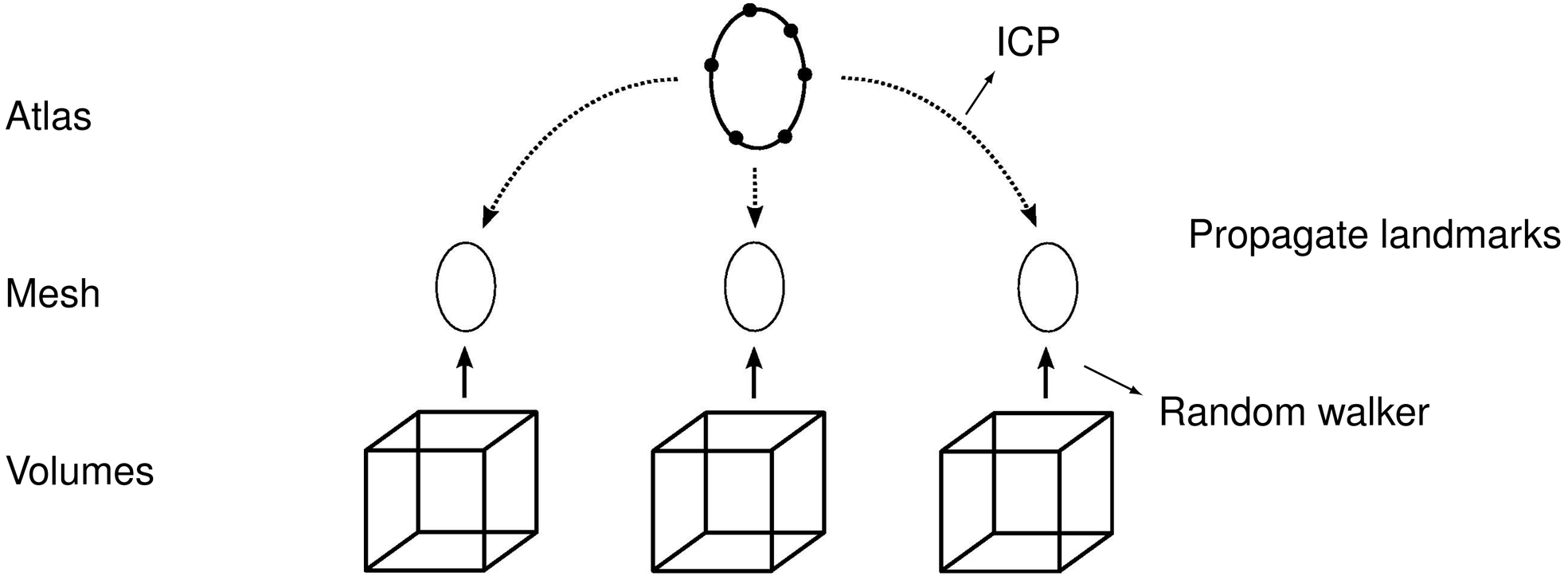

Figure 2: Mesh to mesh

Finding Correspondences: Mesh to Volume

→ Reference shape may introduce bias.

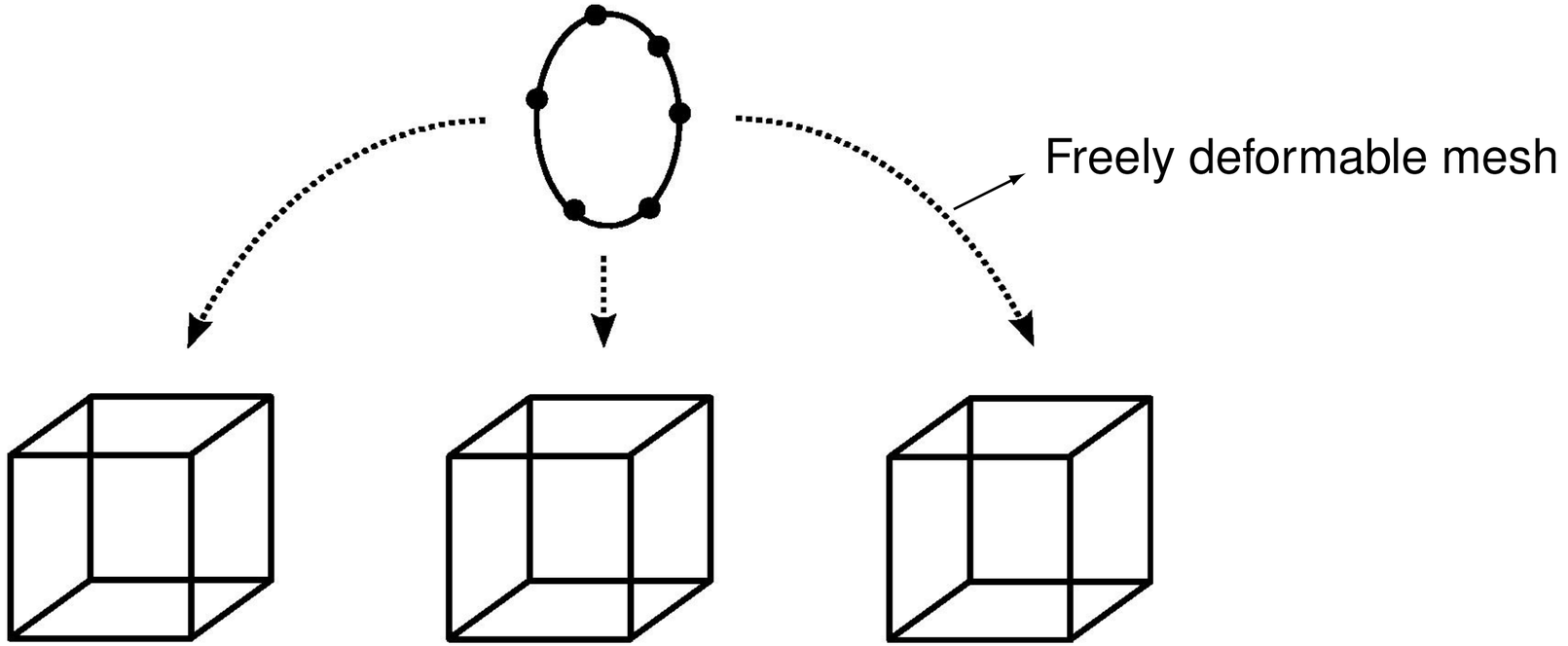

Figure 3: Mesh to volume

Finding Correspondences: Volume to Volume

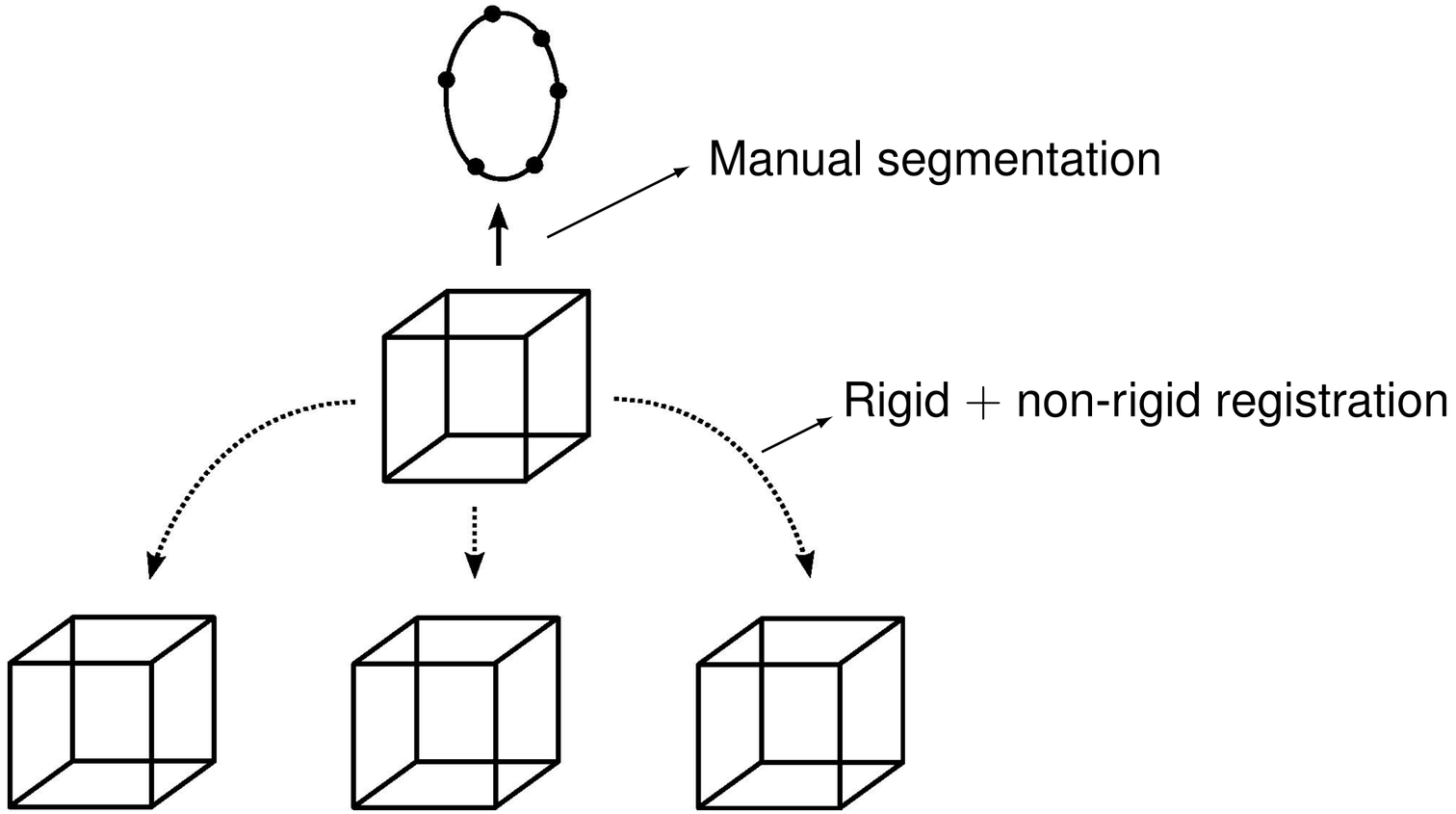

Figure 4: Volume to volume

Appearance Models

Models how the mode looks in the image:

- Boundary-based features (intensity + derivatives)
- Gabor wavelets
- Distances
- SIFT, MOG
- Classifiers, boosting
- Texture information

$\rightarrow$ Delivers a fit / goodness for every landmark

Search Algorithms

Initialization:

- User / interaction
- Histogram
- Generalized Hough transform
- Particle filter
- Bounding box detection

Search Algorithms

Active shape models:

Search strategy based on a point distribution mode

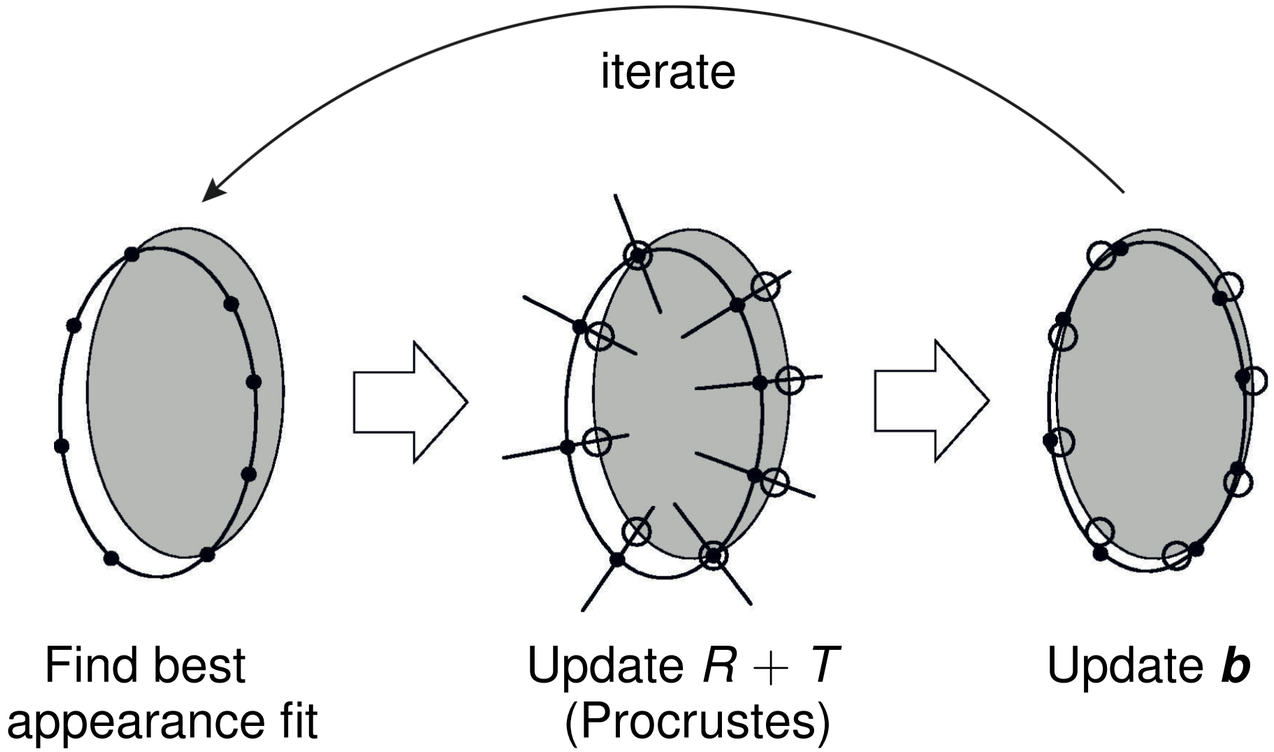

Figure 5: Scheme for active shape model

Search Algorithms

Active shape models:

Search strategy based on a point distribution mode

Active appearance models:

- Combine shape and appearance into a single model
- Use linear system to update parameters

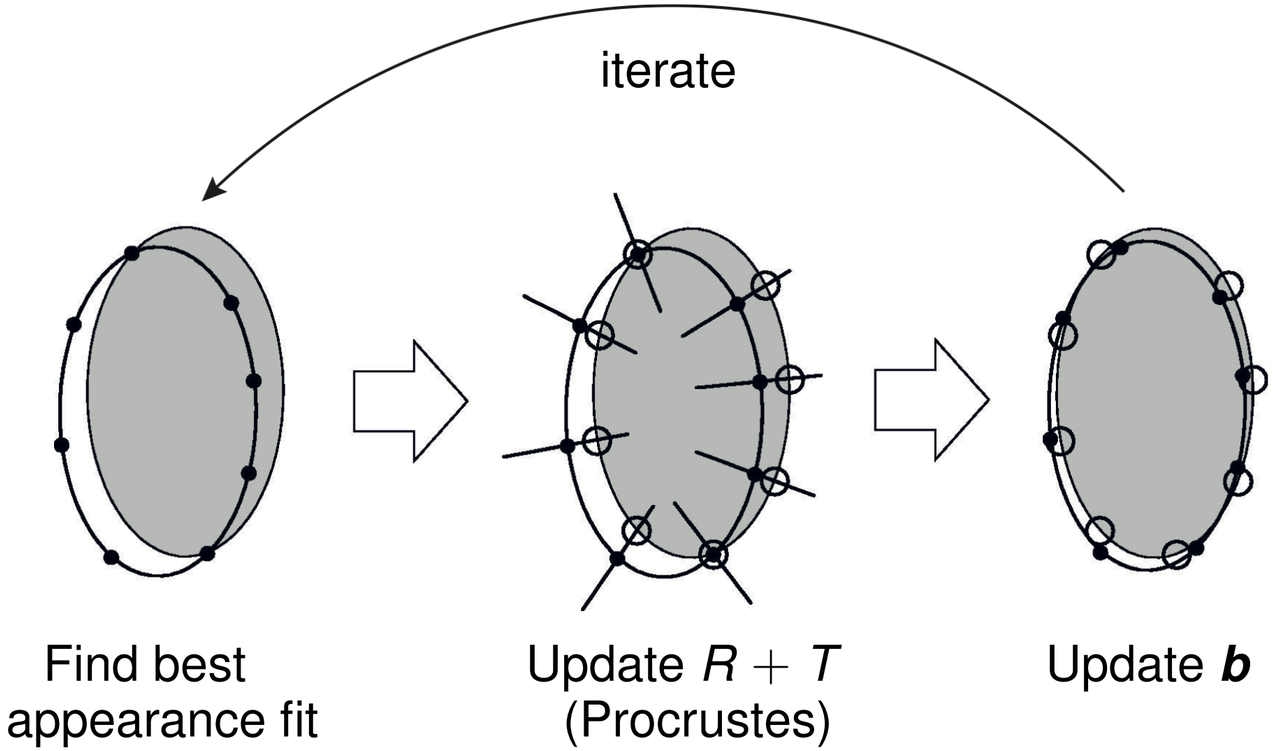

Figure 5: Scheme for active shape model

Applications

- Segmentation
  - Organs (heart, liver, etc.)
  - Bones (vertebrae, knee, femur, etc.)
- Interpretation of shapes
  - Hippocampus
    - Schizophrenia
    - Attention deficit disorder
    - Alzheimer's disease
  - Analysis of aging
- Shape extrapolation
  - 3-D+t heart shape from 2-D+t MRI / US data
  - Complete bone shapes from sparse 3-D data
- And many more applications

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Take Home Messages

- Concepts like GPA and PCA are used to align and analyze the shape for a given point set.
- New data is registered to the corresponding model which can be performed using mesh to mesh, mesh to volume, or volume to volume registration.
- Active shape models and active appearance models are popular concepts for statistical shape models.

Further Readings

These review papers are a good start for learning more about the methods described in this unit:

- Tobias Heimann and Hans-Peter Meinzer. “Statistical Shape Models for 3D Medical Image Segmentation: A Review”. In: *Medical Image Analysis* 13.4 (Aug. 2009), pp. 543–563. DOI: 10.1016/j.media.2009.05.004
- Daniel Cremers, Mikael Rousson, and Rachid Deriche. “A Review of Statistical Approaches to Level Set Segmentation: Integrating Color, Texture, Motion and Shape”. In: *International Journal of Computer Vision* 72.2 (Apr. 2007), pp. 195–215. DOI: 10.1007/s11263-006-8711-1

They also contain lots of references for further reading.