Robust Automatic Co-segmentation of Multiple Medical Images

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Introduction: from segmentation to co-segmentation

+ **Texture-based segmentation**¹:
  - Intra-region texture homogeneity
  - Inter-region texture heterogeneity

CT and atlas data from the AAPM LCTSC dataset

 andre Belongie et al. ICCV, 1998
 andre Cimpoi et al. ICCV, 2015
 shi et al. IEEE Trans. PAML, 2000
 andre Rother et al. CVPR, 2006
 andre Rubio et al. CVPR, 2012

Thoracic CT slice i

Segmentation of slice i
(colors == region labels)
**Introduction: from segmentation to co-segmentation**

+ **Texture-based segmentation**\(^1\):  
  - Intra-region texture homogeneity  
  - Inter-region texture heterogeneity

+ **Texture-based co-segmentation**\(^2\):  
  - Simultaneous segmentation  
  - Inter-image region correspondence

CT and atlas data from the AAPM LCTSC dataset

\(^1\) [Belongie et al. ICCV, 1998]
[Cimpoi et al. ICCV, 2015]
[Shi et al. IEEE Trans. PAML, 2000]

\(^2\) [Rother et al. CVPR, 2006]
[Rubio et al. CVPR, 2012]

\(^3\) [Wang et al. IEEE Trans. PAML, 2010], [Iglesias et al. Med Image Anal, 2015]
Introduction: from segmentation to co-segmentation

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* **Atlas guided segmentation**\(^3\): special case of co-segmentation

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4. [Rother et al. CVPR, 2006]
5. [Rubio et al. CVPR, 2012]
Purpose: Automatic co-segmentation

INPUT:
- CT slice $i$ equipped with provided atlas (labels)
- CT slice $j$ without labels

OUTPUT:
- Automatically generated atlas (labels) of CT slice $j$

+ Provide texture homogeneity information for further image processing tasks (e.g. adaptive denoising\(^1\), registration)
+ Identify (label) organs of interest in query image guided by atlas

\(^1\)Dimitris Floros' talk on Wednesday, August 02: WE-G-201-6
Method: co-segmentation by utilizing texture similarity and atlas

**Patch**: texture element (local signal structure and noise statistics)

**Patch similarity weight**: 
\[ w(P_a, P_b) = \exp \left( - \frac{||P_a - P_b||^2}{\sigma_f^2} \right) \]
Method: co-segmentation by utilizing texture similarity and atlas

**Patch:** texture element (local signal structure and noise statistics)

**Joint weight matrix:**

\[
\begin{array}{c}
A_{ij} \\
A_{ij}^T \\
A_{ij} \\
A_{ij}^T
\end{array}
\]

**Patch similarity weight:**

\[
w(P_a, P_b) = \exp\left(-\frac{||P_a - P_b||^2}{\sigma_f^2}\right)
\]
Result part 1: co-segmentation by texture similarity alone

Provide texture homogeneity information for further image processing tasks (e.g. adaptive denoising, registration)

Co-segmentation via texture similarity and graph spectral embedding and clustering \(^1\)

\(^1\) [Shi et al. IEEE Trans. PAML, 2000]
Observation: Similar textures between heart and aorta

Solution: incorporate label and spatial relationship into joint similarity matrix
Method: co-segmentation for label (atlas) transferring

\( p \) – a subset of heart patches
\( q \) – a subset of aorta patches

\[
\begin{align*}
A_{pp} & \quad A_{pq} \\
A_{qp} & \quad A_{qq}
\end{align*}
\]

Similarity submatrix: texture-only

\[
w(P_a, P_b) = \exp \left( -\frac{||P_a - P_b||^2}{\sigma_f^2} \right)
\]
Method: co-segmentation for label (atlas) transferring

\( p \) – a subset of heart patches
\( q \) – a subset of aorta patches

\[
\begin{align*}
A_{ij}, & A_{ii}, A_{jj}, A_{pp}, A_{pq}, A_{qp}, A_{qq} \\
p \subset I_i, q \subset I_j
\end{align*}
\]

similarity submatrix: with feature, atlas and spatial relationship

\[
w(P_a, P_b) = \exp \left( -\frac{\|P_a - P_b\|_2^2}{\sigma_f^2} - \frac{\|x_a - x_b\|_2^2}{\sigma_s^2} - \frac{1 - \delta(l_a - l_b)}{\sigma_l^2} \right)
\]

\( x_a \) – spatial coordinates of \( P_a \)
\( l_a \) – atlas label of \( P_a \) (if available)
Results part 2: co-segmentation for label (atlas) transferring

Thoracic CT slice $i$

Co-segmentation of slice $i$

Provided labels of slice $i$

Thoracic CT slice $j$

Co-segmentation of slice $j$
Results part 2: co-segmentation for label (atlas) transferring

Thoracic CT slice $i$
Co-segmentation of slice $i$
Provided labels of slice $i$

Thoracic CT slice $j$
Co-segmentation of slice $j$
Transferred labels of slice $j$
– Enable the texture-based co-segmentation for registration and denoising
– Transfer labels from reference image (with atlas labels) to query images

In Progress:
– Transferring labels (atlas info) between different scans/patient
– Transferring labels between different patients
Thank you!

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A framework for evaluation of deformable image registration spatial accuracy using large landmark point sets.

Medical image segmentation by combining graph cuts and oriented active appearance models.

A whole brain fmri atlas generated via spatially constrained spectral clustering.
A. L. Dulmage and N. S. Mendelsohn.  
**Coverings of bipartite graphs.**  

L. Grady and G. Funka-Lea.  
**Multi-label image segmentation for medical applications based on graph-theoretic electrical potentials.**  

**Improved watershed transform for medical image segmentation using prior information.**  


D. L. Pham, C. Xu, and J. L. Prince.

**Current methods in medical image segmentation.**


U. Von Luxburg.

**A tutorial on spectral clustering.**