Image segmentation & Region growing

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Image analyses pipeline

Input images → Structure segmentation

Center detection → Instance segmentation

Region growing → Stage classification

Gene expressions → Segmented ovary → Mean shape

Transform

Segmentation → Classification → Registration → BPDL
Resources

- **Publications:**

- **Implementation:** [https://github.com/Borda/pyImSegm](https://github.com/Borda/pyImSegm)
Supervised and unsupervised segmentation using superpixels, model estimation, and Graph Cut

Image analysis pipeline

1. Structure (tissue) segmentation
   a. computation of superpixels - SLIC
   b. extraction of superpixel-based descriptors;
   c. calculating image-based class probabilities;
   d. spatial regularized superpixel classification using Graph Cut

2. Center detection
   a. center candidate training & prediction
   b. candidate clustering
   c. ellipse fitting

3. Region growing
   a. learning statistical model
   b. region growing
Segmentation method overview

Image segmentation method consisting of the following steps:

1. Computation of superpixels - SLIC
2. Extraction of superpixel-based descriptors;
   a. Color - mean, median, energy, STD
   b. Texture - Leung-Malik filter bank
3. Calculating image-based class probabilities;
   a. Supervised - Random Forest, k-NN, Adaboost, ...
   b. Unsupervised - Gaussian Mixture Model
4. Spatial regularized superpixel classification using Graph Cut
   a. Edge weights - color, features, model
Used datasets - Langerhan islets
Used datasets - Drosophila imaginal discs
Used datasets - Drosophila ovary
Problem formulation

Formulation (standard) as

\[ Y^* = \arg\max_Y P(Y \mid X) = \arg\max_Y \frac{p(X \mid Y) \cdot P(Y)}{p(X)} \]

\[ P(Y) = \prod_{s \in S} h(y_s) \cdot \prod_{(i,j) \in N \subseteq S^2} R(y_i, y_j) \]

\[ Y^* = \arg\max_Y \prod_{i \in S} \left( p(x_i \mid y_i) \cdot h(y_i) \right) \cdot \prod_{(i,j) \in N} R(y_i, y_j) \]

Energy minimisation

\[ Y^* = \arg\min_Y \sum_s -\log \left( \frac{p(x_s \mid y_s) \cdot h(y_s)}{U_s(y_s)} \right) + \sum_{(i,j) \in N} \log R(y_i, y_j) \]
Graph Cut - Edge weight

\[ w_{i,j} = \frac{\tilde{d}_E}{d_E(i,j)} \]

\[ \exp \left( -\frac{d_E(I_i, I_j)}{2\sigma_i^2} \right) \cdot \frac{\tilde{d}_E}{d_E(i,j)} \]

\[ \exp \left( -\frac{d_M(x_i, x_j)}{2\sigma_X^2} \right) \cdot \frac{\tilde{d}_E}{d_E(i,j)} \]

\[ \exp \left( -\frac{d_I(p_i, p_j)}{2\sigma_p^2} \right) \cdot \frac{\tilde{d}_E}{d_E(i,j)} \]
## Segmentation results with SOA (F1-score)

<table>
<thead>
<tr>
<th>Method</th>
<th>Lang. islets</th>
<th>Imaginal disc</th>
<th>Ovary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pixel-wise Supervised</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weka $^{44}$</td>
<td>0.7374</td>
<td>0.6923</td>
<td>0.5800</td>
</tr>
<tr>
<td>Weka &amp; GC(0, 100)</td>
<td>0.7373</td>
<td>0.6887</td>
<td>0.5810</td>
</tr>
<tr>
<td>Weka &amp; GC(1, 50)</td>
<td>0.7376</td>
<td>0.6887</td>
<td>0.5965</td>
</tr>
<tr>
<td>Weka &amp; GC(10, 50)</td>
<td>0.6935</td>
<td>0.6887</td>
<td>0.1395</td>
</tr>
<tr>
<td>Weka &amp; GC(50, 100)</td>
<td>0.6862</td>
<td>0.6850</td>
<td>0.6007</td>
</tr>
<tr>
<td>NPA $^{33}$</td>
<td>0.8420</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ideal segm. $Y_A$</td>
<td>0.8590</td>
<td>0.9696</td>
<td>0.9067</td>
</tr>
<tr>
<td>Supertextons $^{17}$</td>
<td>-</td>
<td>-</td>
<td>0.7488</td>
</tr>
<tr>
<td>Our RF</td>
<td>0.8565</td>
<td>0.8181</td>
<td>0.8201</td>
</tr>
<tr>
<td>Our RF &amp; GC</td>
<td>0.8570</td>
<td>0.8229</td>
<td>0.8600</td>
</tr>
<tr>
<td><strong>Superpixels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Our GMM</td>
<td>0.5358</td>
<td>0.7542</td>
<td>0.5967</td>
</tr>
<tr>
<td>Our GMM &amp; GC</td>
<td>0.5465</td>
<td>0.7644</td>
<td>0.6039</td>
</tr>
<tr>
<td>Our GMM [gr]</td>
<td>0.5682</td>
<td>0.7301</td>
<td>0.6009</td>
</tr>
<tr>
<td>Our GMM [gr] &amp; GC</td>
<td>0.5816</td>
<td>0.7564</td>
<td>0.6083</td>
</tr>
</tbody>
</table>
Advantage of using Graph Cut
Supervised vs Unsupervised

Weka

Annotation

our RF & GC

our GMM & GC
Unsupervised with Graph Cut

Weka segm. & CG  input image  our segm. GMM  our GMM & CG
Detection and localization of Drosophila egg chambers in microscopy images

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Center detections
Features for center detection

- Label histogram

- Ray features
Ellipse fitting

Maximize likelihood

\[ \prod_{i \in \Omega_F} P_F(Y_i) \cdot \prod_{i \in \Omega \setminus \Omega_F} P_B(Y_i) \]
Region growing using superpixels with learned shape prior

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Region growing - variational framework

Formulated as:

\[ P(g(s) \mid y, M) = \frac{1}{Z(M, y)} P_y(g \mid y) P_m(g \mid M) P_R(g) \]

Where:

\[ P_y(g \mid y) = \prod_{i \in \Omega} P_y\left(g(s(i)) \mid y(s(i))\right) = \prod_{s \in S} P_y\left(g(s) \mid y(s)\right)^{|\Omega_s|} \]

\[ P_m(g \mid M) = \prod_{i \in \Omega} P_m\left(g(s(i)) \mid M\right) = \prod_{s \in S} P_m\left(g(s) \mid M\right)^{|\Omega_s|} \]

\[ P_R(g) = \prod_{(u,v) \in N_s} H(g(u), g(v)) \]

Resolves in energy minimisation:

\[ E'(g) = \sum_{s \in S} |\Omega_s| \left[ D_s(g(s)) + \beta V_s(g(s)) \right] + \sum_{(u,v) \in N_s} \gamma B(g(u), g(v)) \]
Appearance model

Associating a probability for each pixel / superpixel whether it belongs to an object or not

\[ P_y(g(s)|y_s) = \begin{cases} 
  P_y(y_s) & \text{for } g(s) \neq 0 \\
  1 - P_y(y_s) & \text{for } g(s) = 0 
\end{cases} \]
Shape model & prior

\[ p_r(r) = \rho(r) = \sum_{j=1}^{M} w_j f_j(r) \]

with \[ f_j(r(i)) = \frac{1}{\sigma_{i,j} \sqrt{2\pi}} \exp \left( -\frac{(r(i) - \mu_{i,j})^2}{2\sigma_{i,j}^2} \right) \]

and \[ \sum_{j} w_j = 1 \]

\[ q(s, m_k) = \int_{-\infty}^{\delta} \rho(r) \, dr = 1 - \int_{0}^{\delta} \rho(r) \, dr \]
Mixture model

\[ P_m(g(s) = k \mid M) = \begin{cases} q(s, m_k) & \text{for } k > 0 \\ \Pi_l (1 - q(s, m_l)) & \text{for } k = 0 \end{cases} \]
Region growing - optimisation

- Greedy
- Multi-class Graph Cut
- Binary Graph Cut
- Object swapping
## Result compare to SOA

<table>
<thead>
<tr>
<th>Method</th>
<th>Jaccard</th>
<th>accuracy</th>
<th>$F_1$ score</th>
<th>precision</th>
<th>recall</th>
<th>time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed</td>
<td>0.5705</td>
<td>0.9246</td>
<td>0.9246</td>
<td>0.9246</td>
<td>0.9246</td>
<td>5</td>
</tr>
<tr>
<td>Watershed (w. morph.)</td>
<td>0.5705</td>
<td>0.9270</td>
<td>0.9198</td>
<td>0.9136</td>
<td>0.9327</td>
<td>7</td>
</tr>
<tr>
<td>Morph. snakes (image)</td>
<td>0.4251</td>
<td>0.8769</td>
<td>0.8070</td>
<td>0.9053</td>
<td>0.7987</td>
<td>784</td>
</tr>
<tr>
<td>Morph. snakes ($P_y$)</td>
<td>0.6494</td>
<td>0.8812</td>
<td>0.8812</td>
<td>0.8812</td>
<td>0.8812</td>
<td>968</td>
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<tr>
<td>Graph Cut (pixel-level)</td>
<td>0.7143</td>
<td>0.9204</td>
<td>0.9204</td>
<td>0.9204</td>
<td>0.9204</td>
<td>15</td>
</tr>
<tr>
<td>Graph Cut (superpixels)</td>
<td>0.3164</td>
<td>0.8643</td>
<td>0.8643</td>
<td>0.8643</td>
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<td>3</td>
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<tr>
<td>RG2Sp (greedy)</td>
<td>0.7527</td>
<td>0.9577</td>
<td>0.9577</td>
<td>0.9577</td>
<td>0.9577</td>
<td>72</td>
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<tr>
<td>RG2Sp (Graph Cut)</td>
<td>0.7544</td>
<td>0.9568</td>
<td>0.9568</td>
<td>0.9568</td>
<td>0.9568</td>
<td>9</td>
</tr>
</tbody>
</table>
Conclusion

● Presented 3 image methods
  ○ Image segmentation on superpixels
    ■ supervised
    ■ Partially-supervised
    ■ unsupervised
  ○ Center detection on segmented images
  ○ Region growing with shape prior

● Future work
  ○ Compte image analysis pipeline
  ○ Explore Instance segmentation with NN
  ○ ...

