Image segmentation & Region growing

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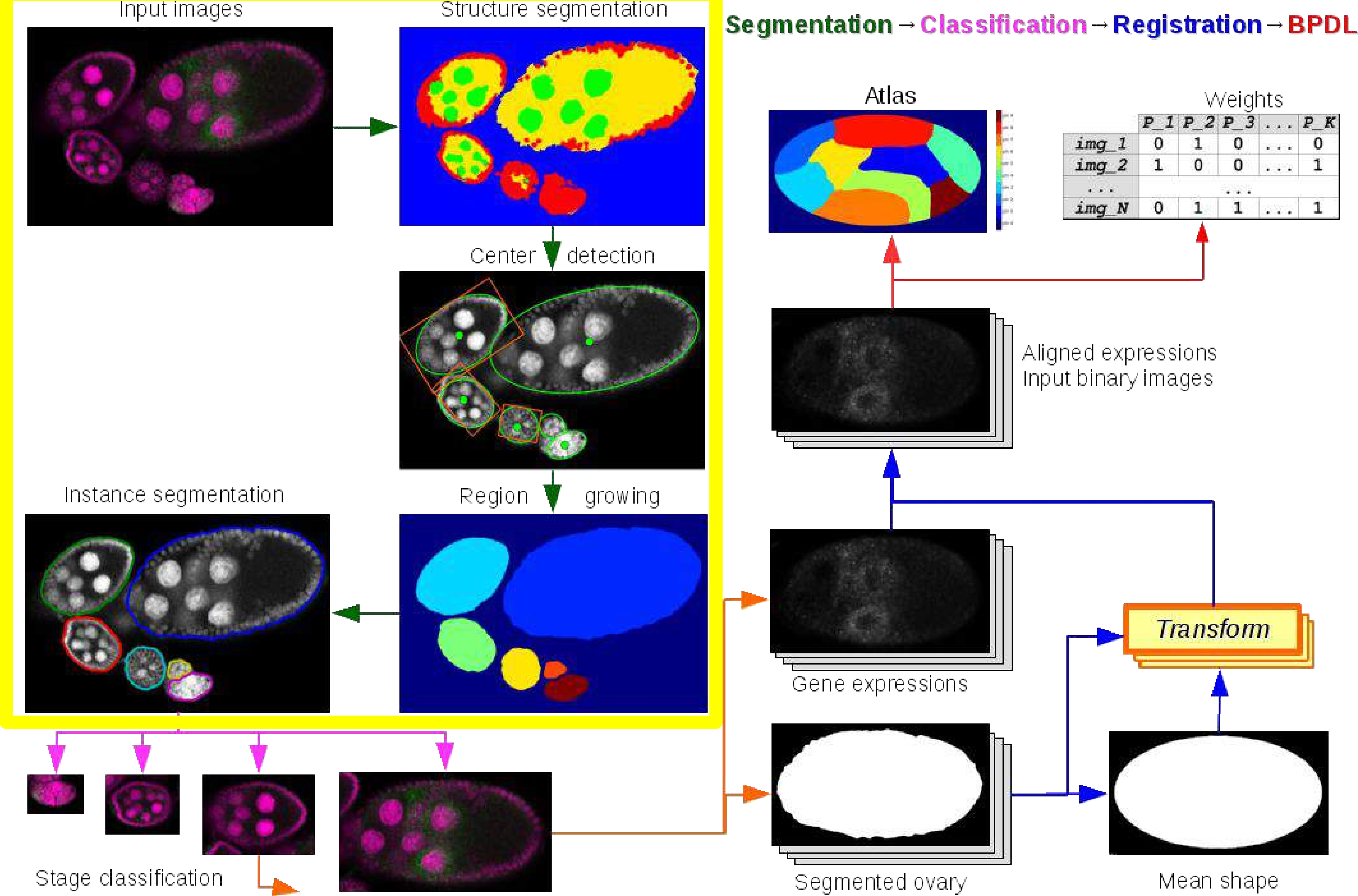
Image analyses pipeline



Resources

- Publications:
  - Borovec J., Svihlik J., Kybic J., Habart D. (2017). **Supervised and unsupervised segmentation using superpixels, model estimation, and Graph Cut.** SPIE Journal of Electronic Imaging 26(6), 061610, http://doi.org/10.1117/1.JEI.26.6.061610
  - Borovec J., Kybic J., Nava R. (2017) **Detection and Localization of Drosophila Egg Chambers in Microscopy Images.** In: Wang Q., Shi Y., Suk HI., Suzuki K. (eds) Machine Learning in Medical Imaging. MLMI 2017. LNCS, vol 10541. Springer, Cham. http://doi.org/10.1007/978-3-319-67389-9_3
  - Borovec J., Kybic J., Sugimoto, A. (2017). **Region growing using superpixels with learned shape prior.** SPIE Journal of Electronic Imaging 26(6), 061611, http://doi.org/10.1117/1.JEI.26.6.061611
- Implementation: https://github.com/Borda/pyImSegm

Supervised and unsupervised segmentation using superpixels, model estimation, and Graph Cut

Jiří Borovec, Jan Švihlík, Jan Kybic, David Habart, "**Supervised and unsupervised segmentation using superpixels, model estimation, and graph cut,**" Journal Electron. Imaging 26(6), 061610 (2017), DOI: 10.1117/1.JEI.26.6.061610.

Image analysis pipeline

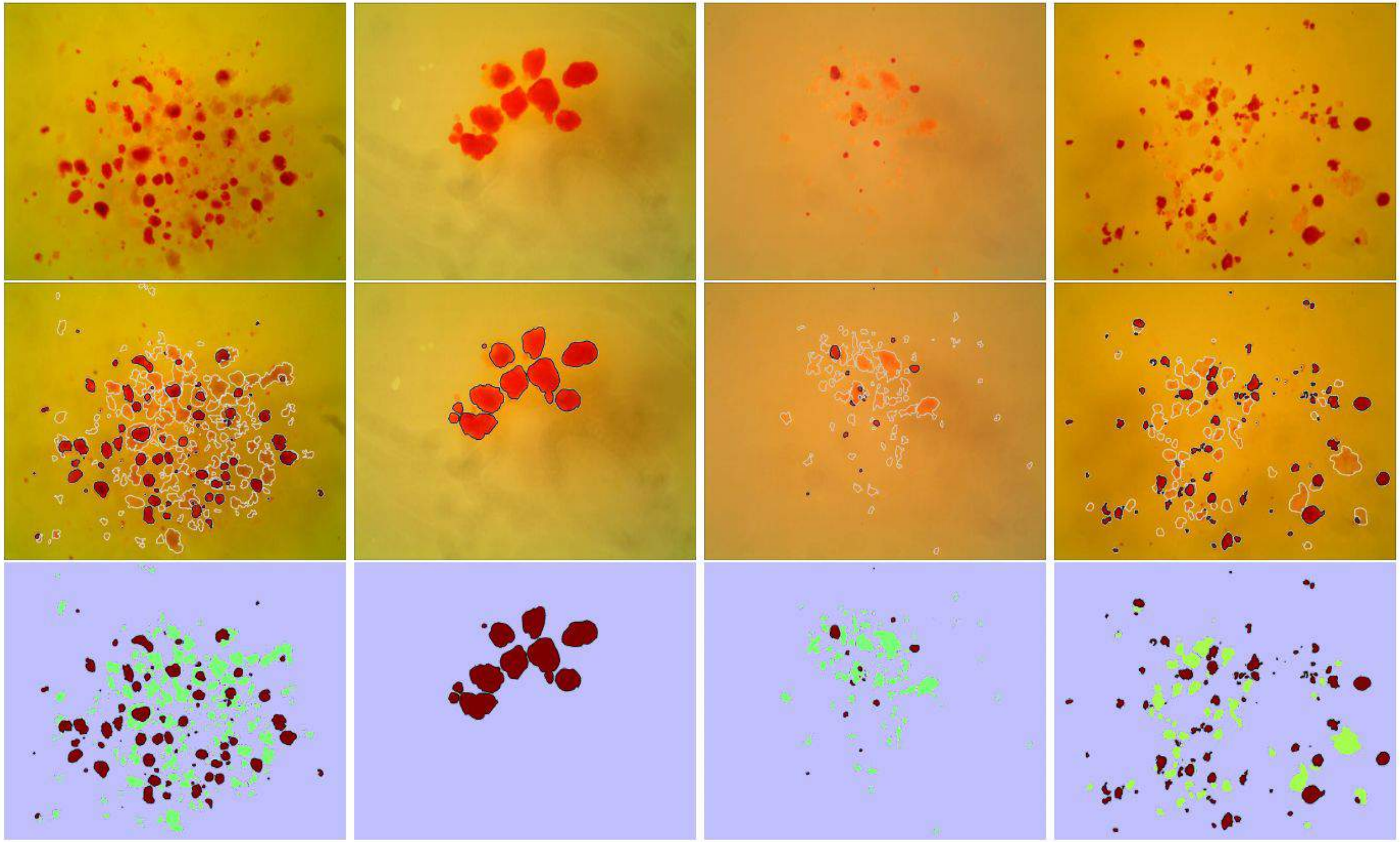
1. Structure (tissue) segmentation
    a. computation of superpixels - SLIC
    b. extraction of superpixel-based descriptors;
    c. calculating image-based class probabilities;
    d. spatial regularized superpixel classification using Graph Cut
2. Center detection
    a. center candidate training & prediction
    b. candidate clustering
    c. ellipse fitting
3. Region growing
    a. learning statistical model
    b. region growing

Segmentation method overview

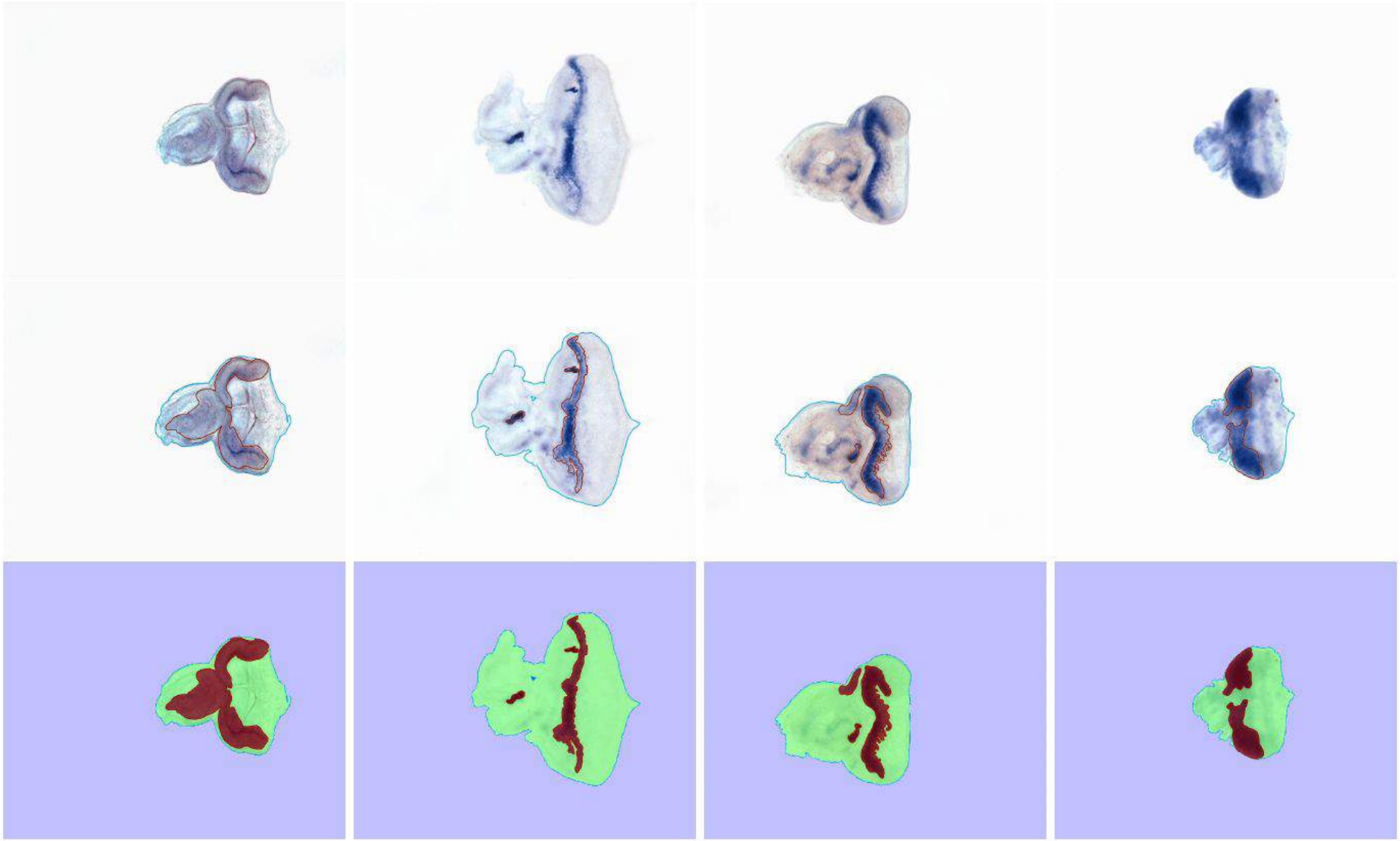
Image segmentation method consisting of the following steps:

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

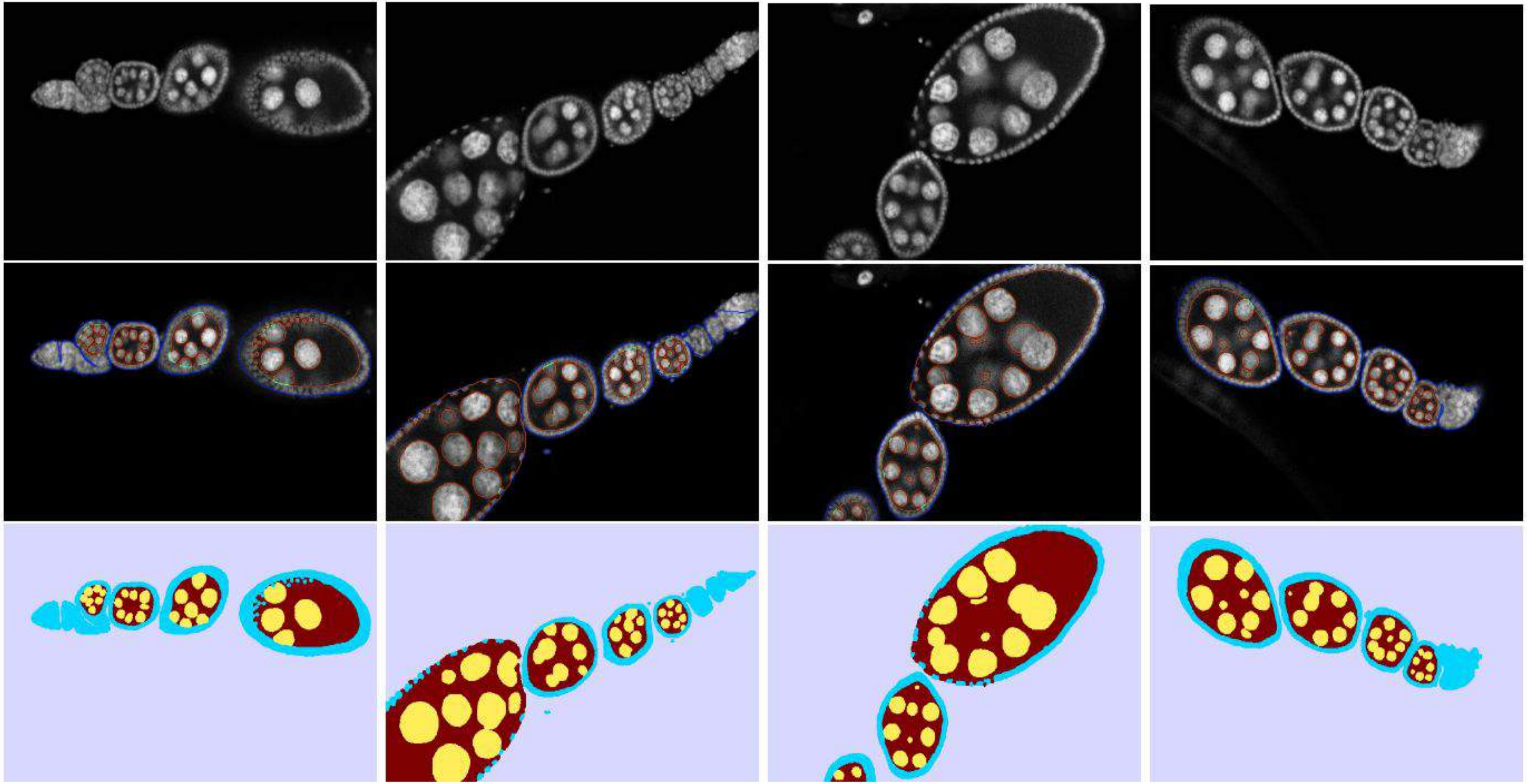
Used datasets - Langerhan islets

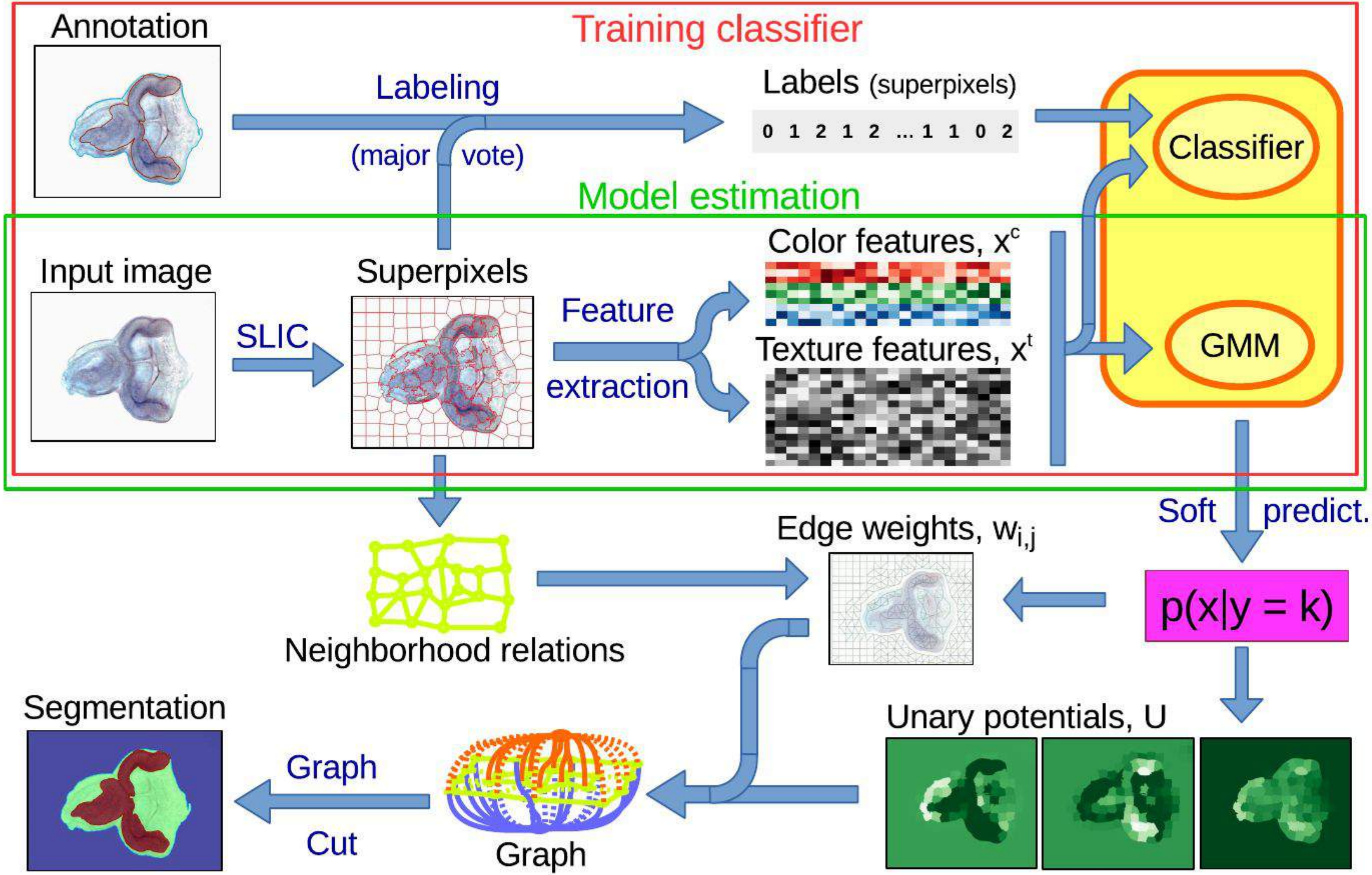


Used datasets - Drosophila imaginal discs



Used datasets - Drosophila ovary





Training classifier
Annotation
Labeling
(major vote)
Labels (superpixels)
0 1 2 1 2 ... 1 1 0 2
Classifier
Model estimation
Input image
SLIC
Superpixels
Feature extraction
Color features, x^c
Texture features, x^t
GMM
Soft predict.
Edge weights, $w_{i,j}$
$p(x|y = k)$
Neighborhood relations
Unary potentials, U
Segmentation
Graph Cut
Graph

Problem formulation

Formulation (standard) as

$$Y^* = \arg\max_Y \, P(Y|X) = \arg\max_Y \, \frac{p(X|Y) \cdot P(Y)}{p(X)}$$

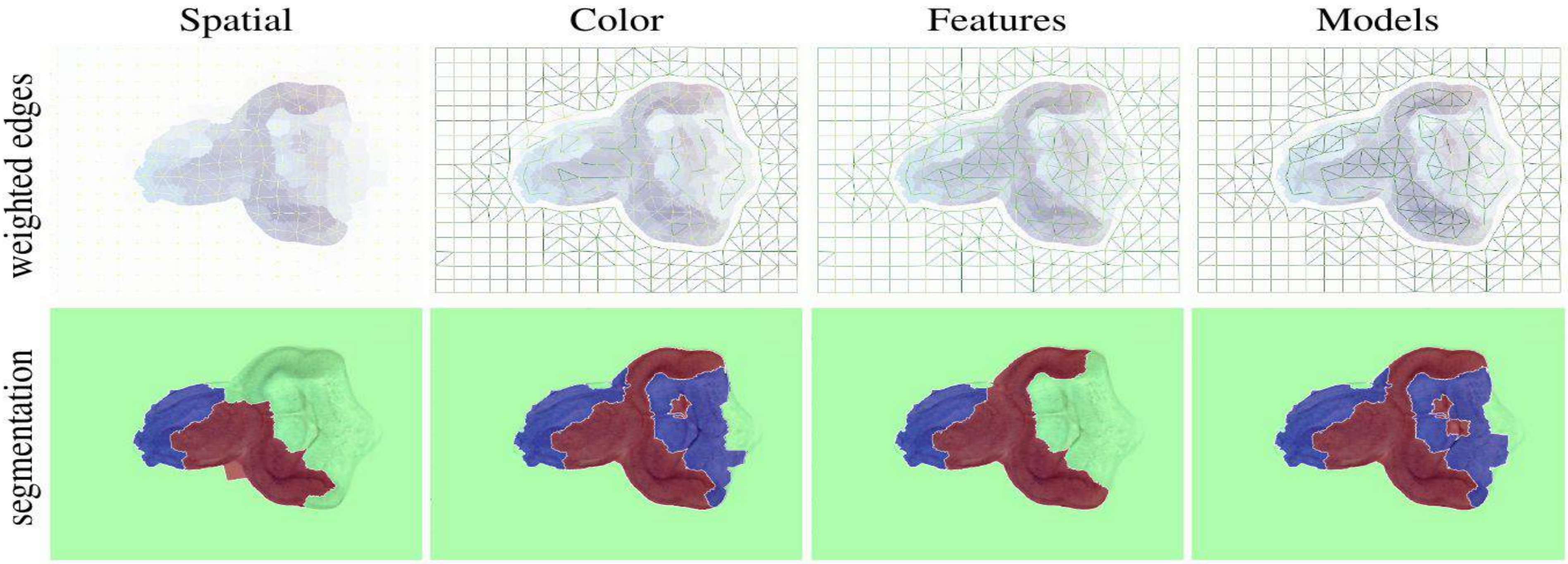
$$P(Y) = \prod_{s \in S} h(y_s) \cdot \prod_{(i,j) \in \mathcal{N} \subseteq S^2} R(y_i, y_j)$$

$$Y^* = \arg\max_Y \, \prod_{i \in S} \left(p(\boldsymbol{x}_i|y_i) \cdot h(y_i)\right) \cdot \prod_{(i,j) \in \mathcal{N}} R(y_i, y_j)$$

Energy minimisation

$$Y^* = \arg\min_Y \, \sum_s \underbrace{-\log\left(p(\boldsymbol{x}_s|y_s) \cdot h(y_s)\right)}_{U_s(y_s)} + \sum_{(i,j) \in \mathcal{N}} \underbrace{-\log R(y_i, y_j)}_{\beta w_{i,j} B(y_i, y_j)}$$

Graph Cut - Edge weight

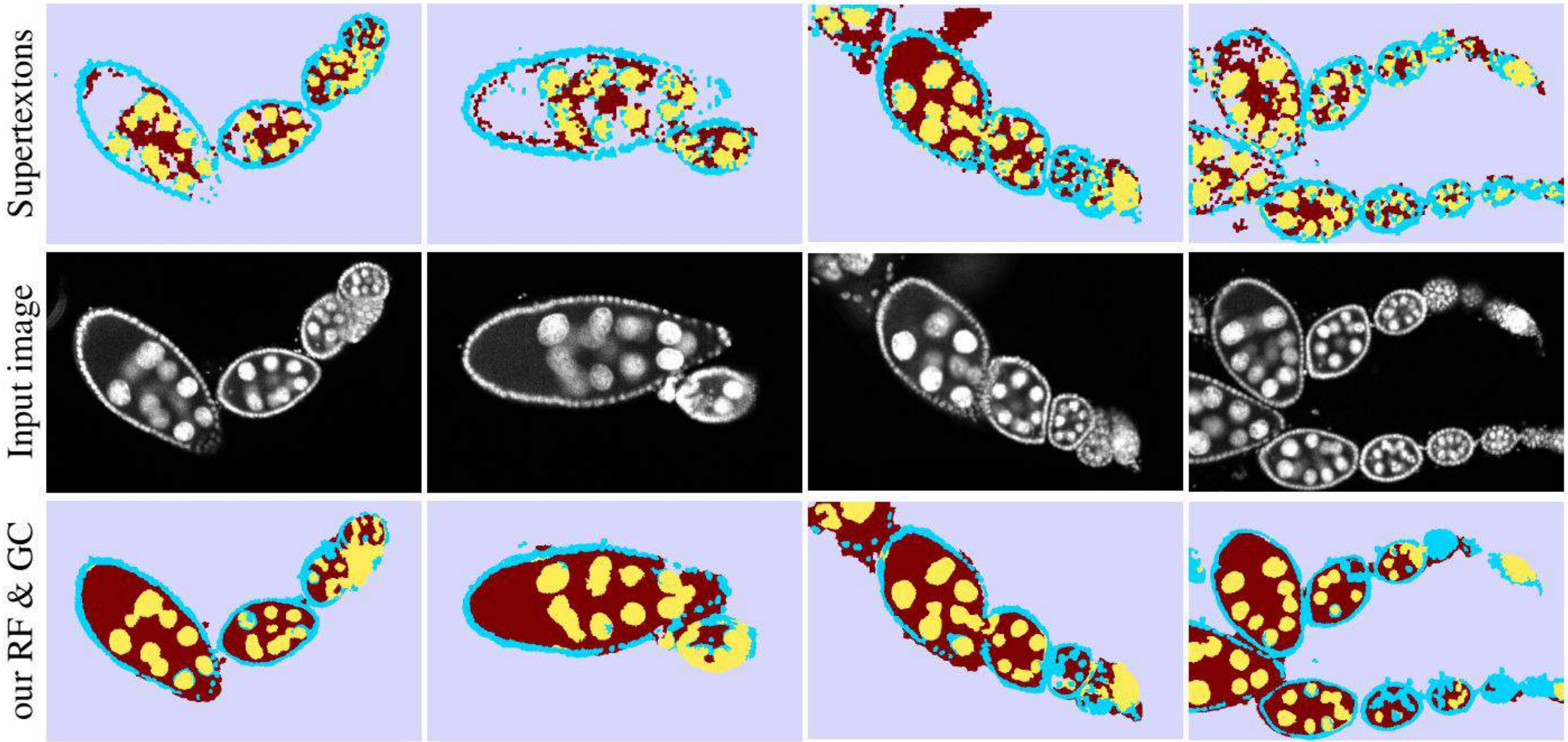


$$w_{i,j} = \frac{\bar{d}_E^S}{d_E(i,j)} \qquad \exp\left(-\frac{d_E(\bar{I}_i,\bar{I}_j)}{2\sigma_c^2}\right)\cdot\frac{\bar{d}_E^S}{d_E(i,j)} \qquad \exp\left(-\frac{d_M(\boldsymbol{x}_i,\boldsymbol{x}_j)}{2\sigma_X^2}\right)\cdot\frac{\bar{d}_E^S}{d_E(i,j)} \qquad \exp\left(-\frac{d_T(p_i,p_j)}{2\sigma_p^2}\right)\cdot\frac{\bar{d}_E^S}{d_E(i,j)}$$

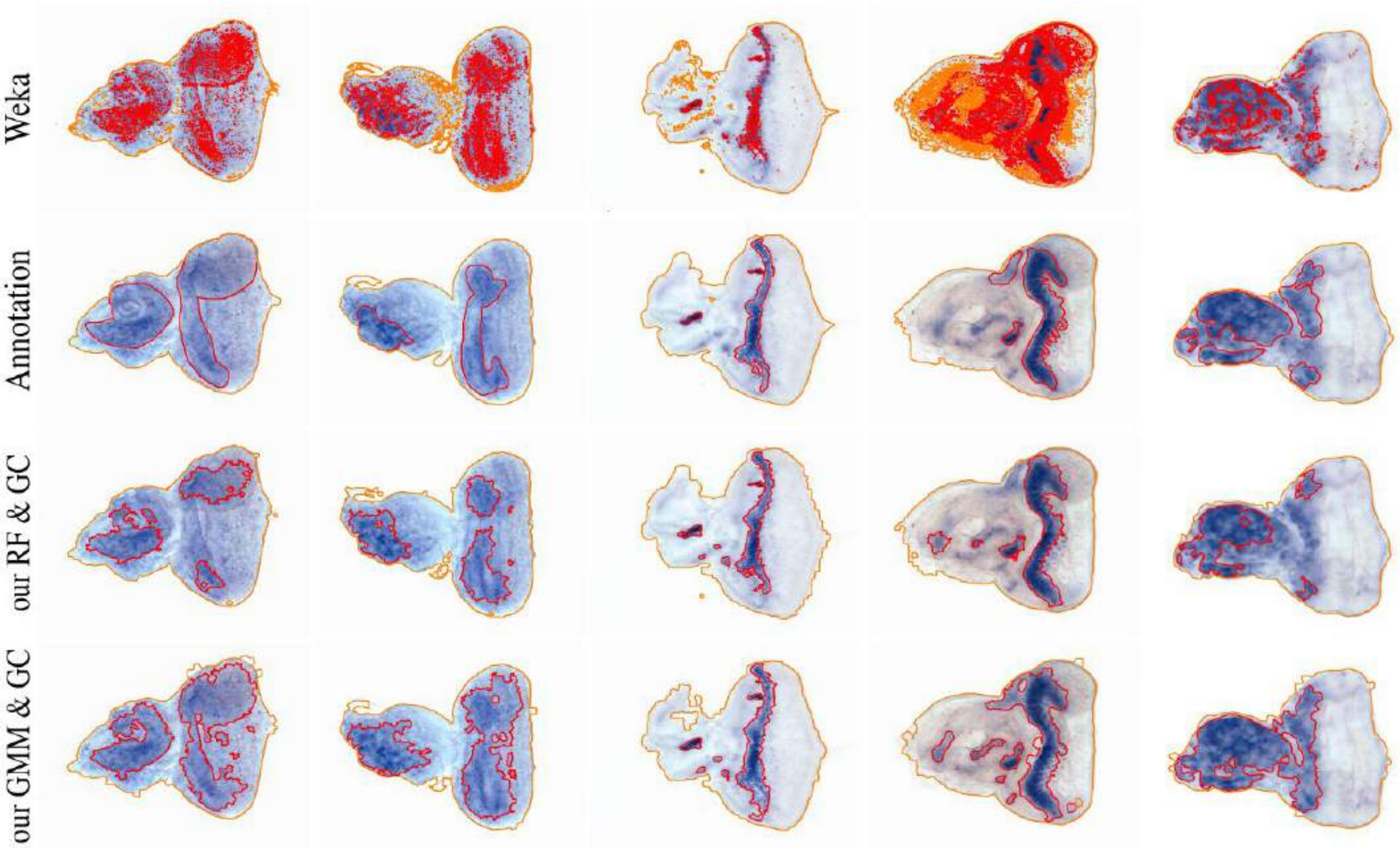
Segmentation results with SOA (F1-score)

		Method	Lang. islets	imaginal disc	ovary
Pixel-wise	Supervised	Weka[44]	0.7374	0.6923	0.5800
		Weka & GC(0, 100)	0.7373	0.6887	0.5810
		Weka & GC(1, 50)	0.7376	0.6887	0.5965
		Weka & GC(10, 50)	0.6935	0.6887	0.1395
		Weka & GC(50, 100)	0.6862	0.6850	0.6007
		NPA[33]	0.8420	-	-
Superpixels		ideal segm. Y_A	0.8590	0.9696	0.9067
		Supertextons[17]	-	-	0.7488
		our RF	0.8565	0.8181	0.8201
		our RF & GC	0.8570	0.8229	0.8600
	Unsuper.	our GMM	0.5358	0.7542	0.5967
		our GMM & GC	0.5465	0.7644	0.6039
		our GMM [gr]	0.5682	0.7301	0.6009
		our GMM [gr] & GC	0.5816	0.7564	0.6083

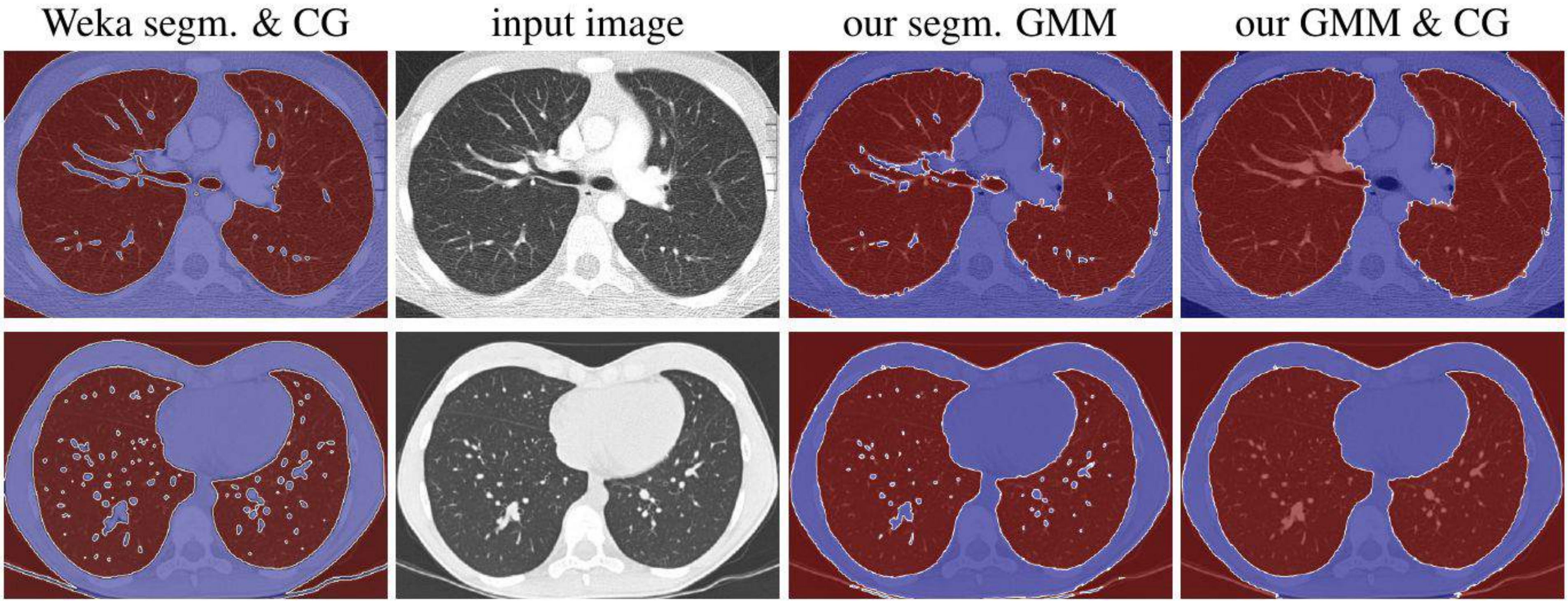
Advantage of using Graph Cut



Supervised vs Unsupervised



Unsupervised with Graph Cut



Detection and localization of Drosophila egg chambers in microscopy images

Borovec J., Kybic J., Nava R. (2017) **Detection and Localization of Drosophila Egg Chambers in Microscopy Images**. In: Machine Learning in Medical Imaging. LNCS, vol 10541. Springer, DOI: 10.1007/978-3-319-67389-9_3

Image analysis pipeline

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    a. learning statistical model
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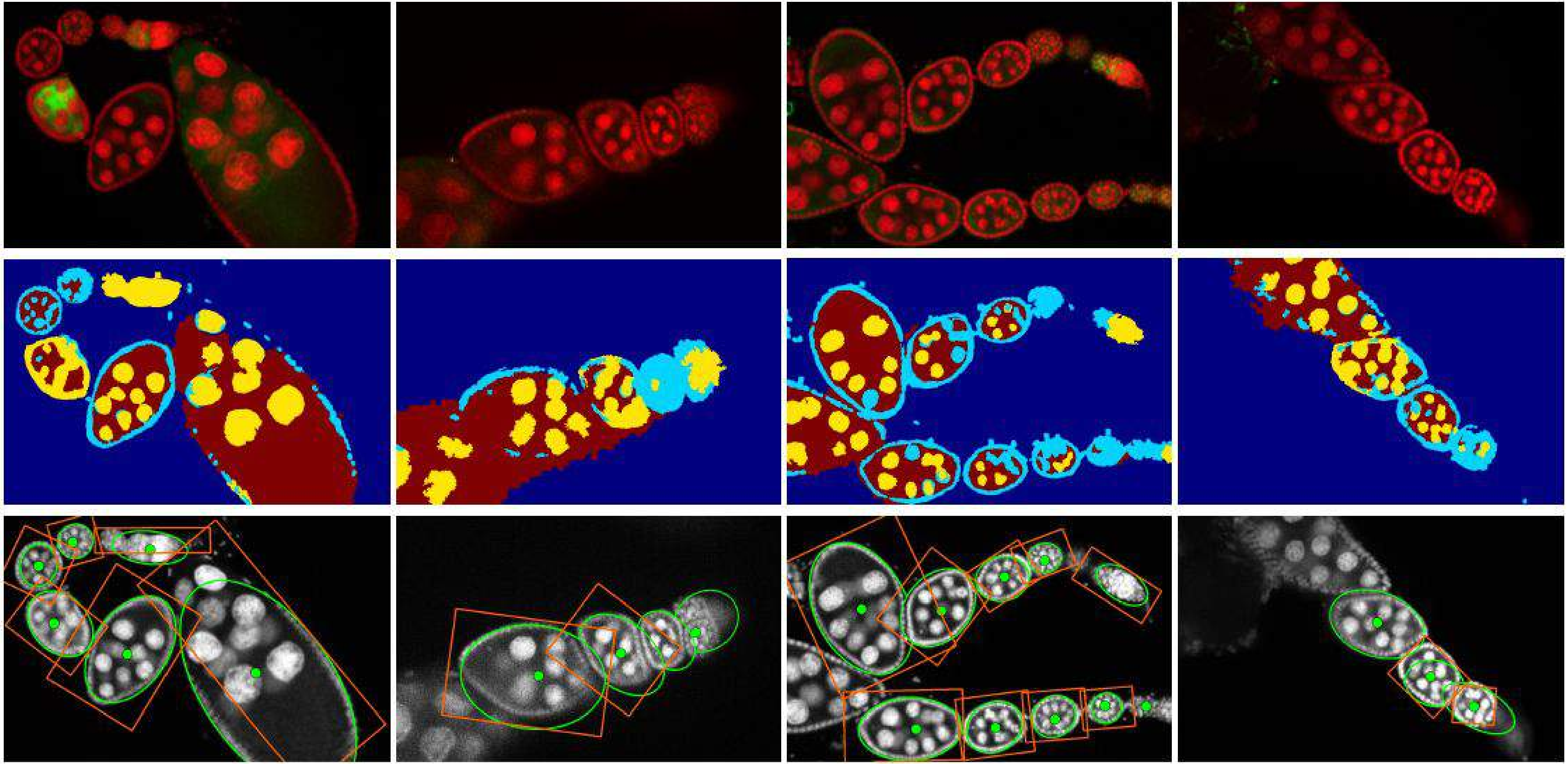
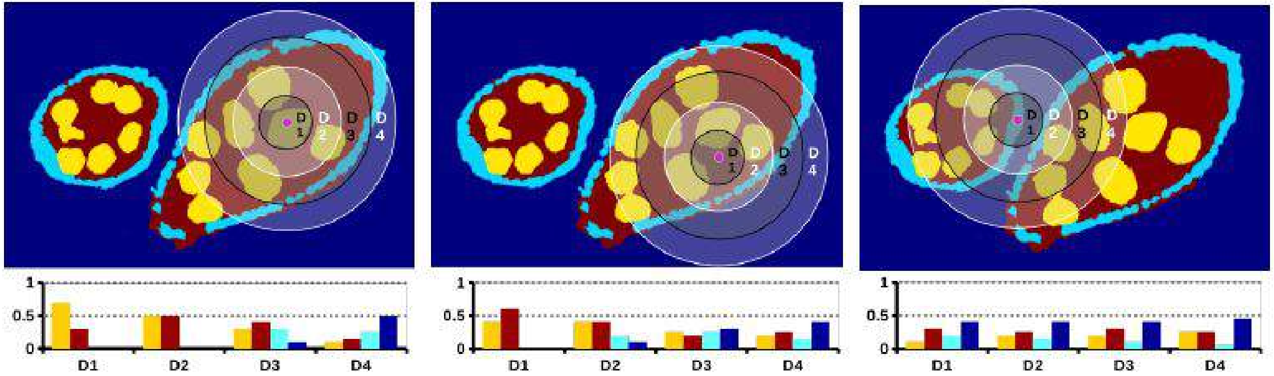
Center detections

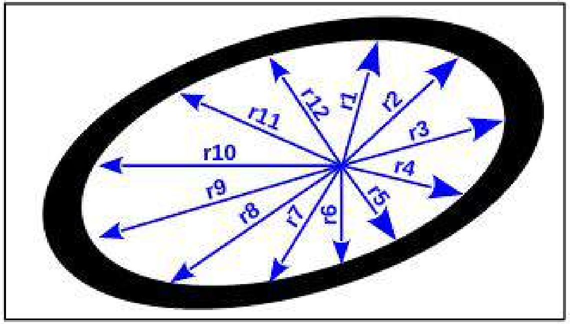


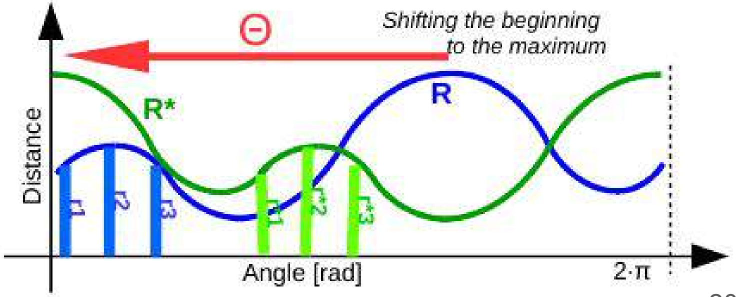
Features for center detection

- Label histogram



- Ray features

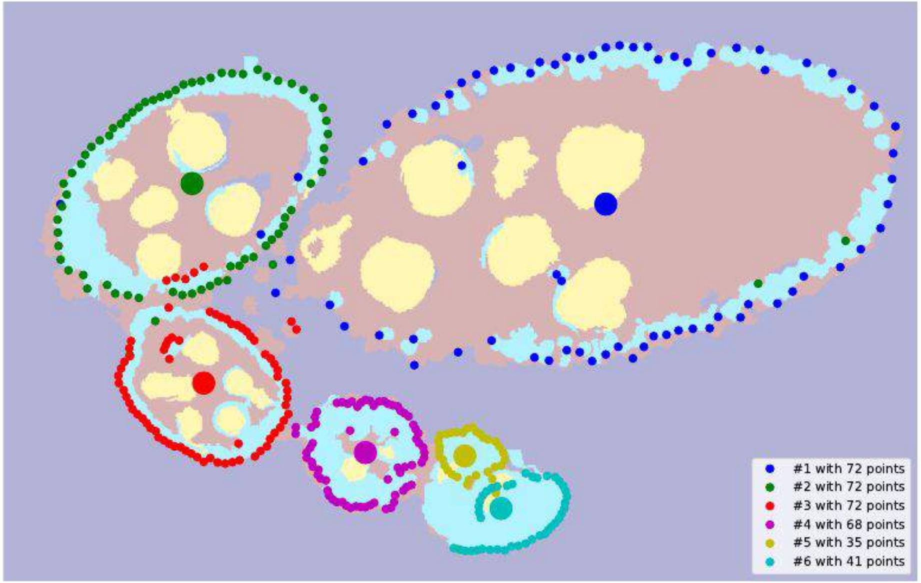


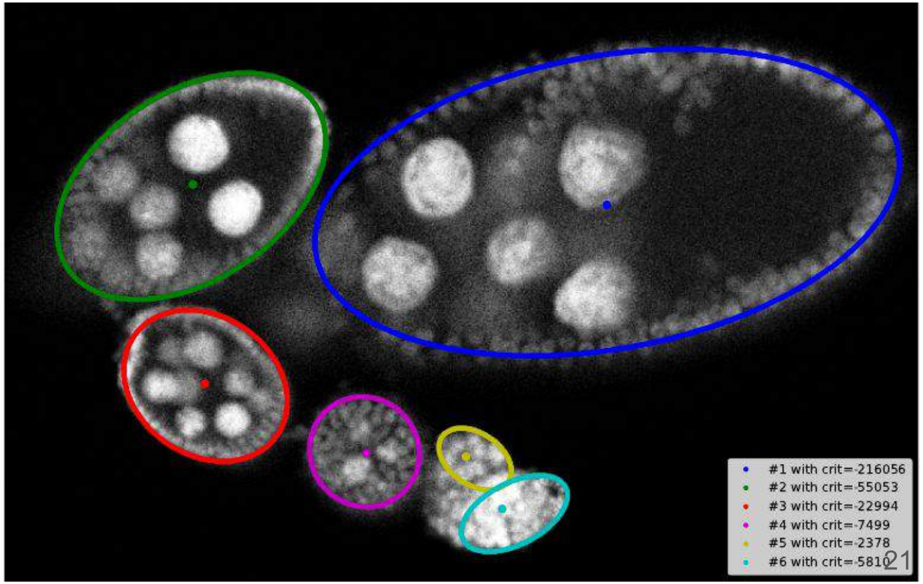


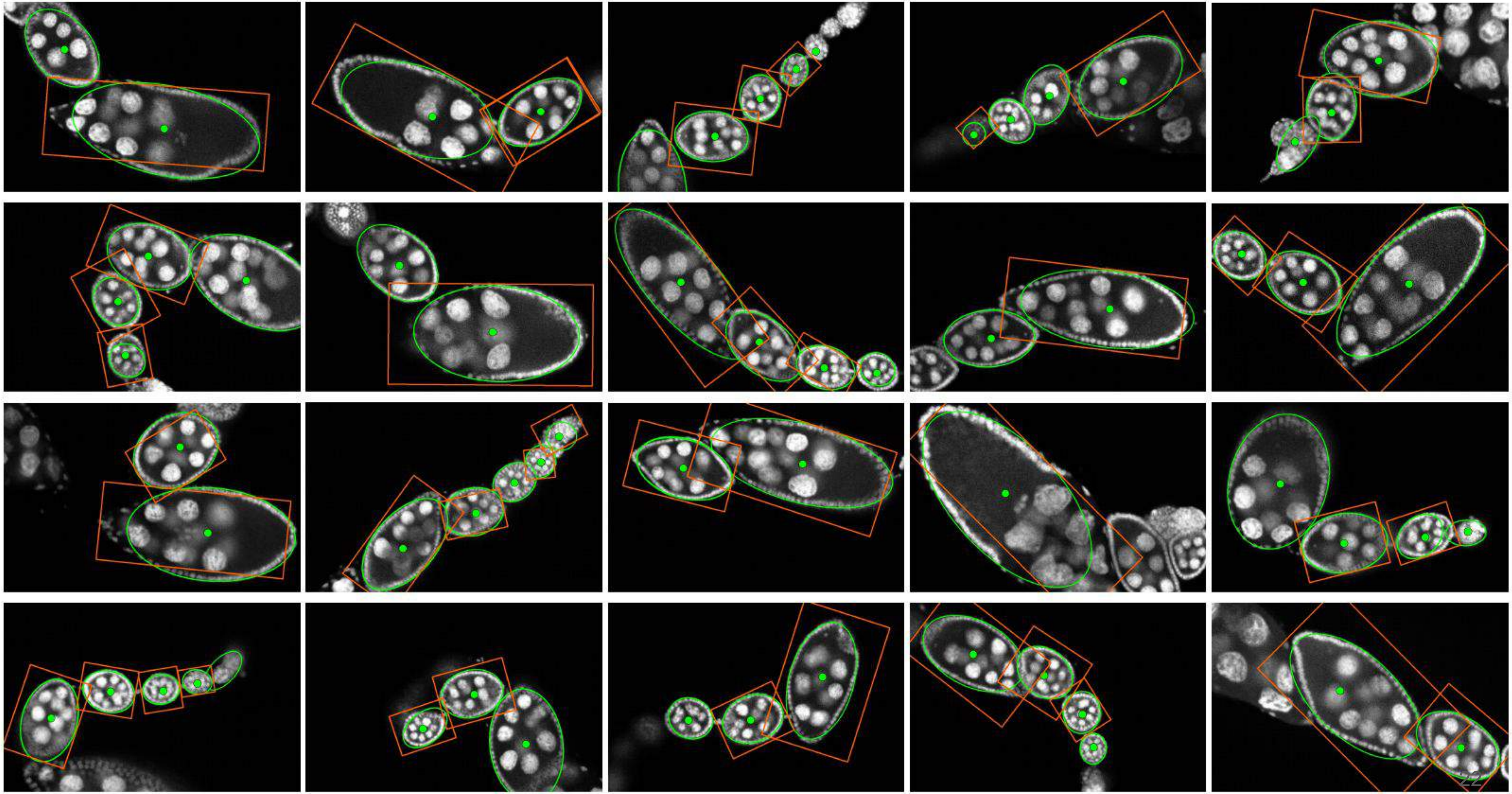
Ellipse fitting

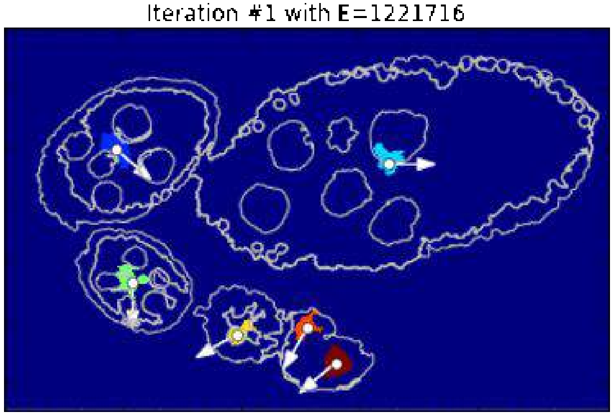
Maximize likelihood

$$\prod_{i \in \Omega_F} P_F(Y_i) \cdot \prod_{i \in \Omega \setminus \Omega_F} P_B(Y_i)$$









Region growing using superpixels with learned shape prior

Jiří Borovec, Jan Kybic, Akihiro Sugimoto, “**Region growing using superpixels with learned shape prior,**“ Journal Electron. Imaging 26(6), 061610 (2017), DOI: 10.1117/1.JEI.26.6.061611.

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Region growing - variational framework

Formulated as:

$$P\big(g(s) \mid y, \boldsymbol{M}\big) = \frac{1}{Z(\boldsymbol{M}, y)} P_y(g \mid y) P_m(g \mid \boldsymbol{M}) P_R(g)$$

Where:

$$P_y(g \mid y) = \prod_{i \in \Omega} P_y\Big(g\big(s(i)\big) \mid y\big(s(i)\big)\Big) = \prod_{s \in S} P_y\big(g(s) \mid y(s)\big)^{|\Omega_s|}$$

$$P_m(g \mid \boldsymbol{M}) = \prod_{i \in \Omega} P_m\Big(g\big(s(i)\big) \mid \boldsymbol{M}\Big) = \prod_{s \in S} P_m\Big(g(s) \mid \boldsymbol{M}\Big)^{|\Omega_s|}$$

$$P_R(g) = \prod_{(u,v) \in \mathcal{N}_S} H\big(g(u), g(v)\big)$$

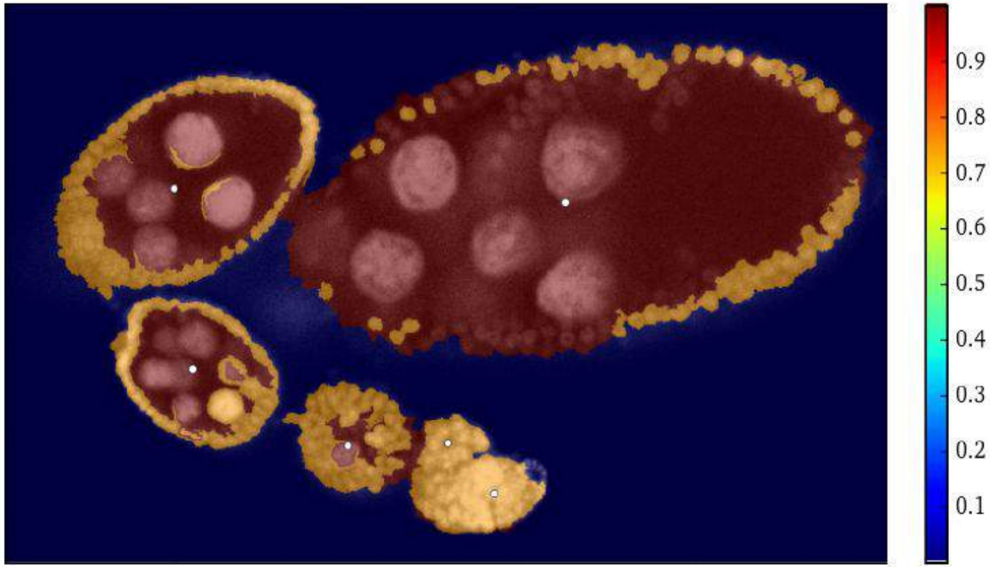
Resolves in energy minimisation:

$$E^{'}(g) = \sum_{s \in S} |\Omega_s| \Big[D_s\big(g(s)\big) + \beta V_s\big(g(s)\big)\Big] + \sum_{(u,v) \in \mathcal{N}_S} \gamma B\big(g(u), g(v)\big)$$

Appearance model

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

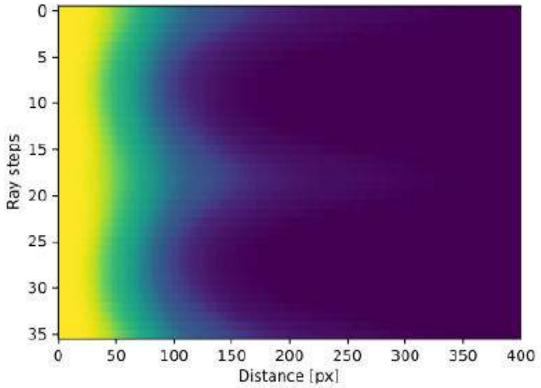
$$P_y(g(s)|y_s) = \begin{cases} P_y(y_s) & \text{for } g(s) \neq 0 \\ 1 - P_y(y_s) & \text{for } g(s) = 0 \end{cases}$$

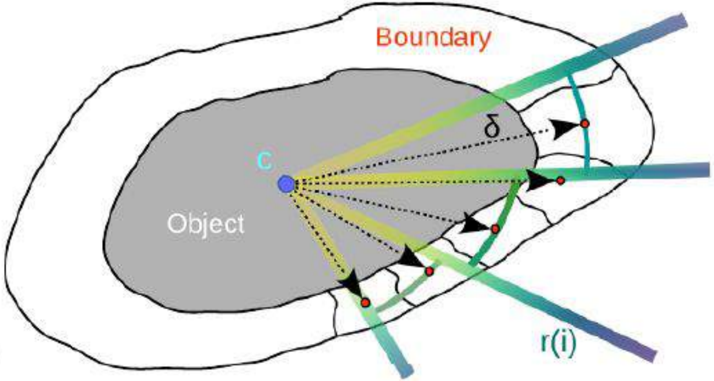


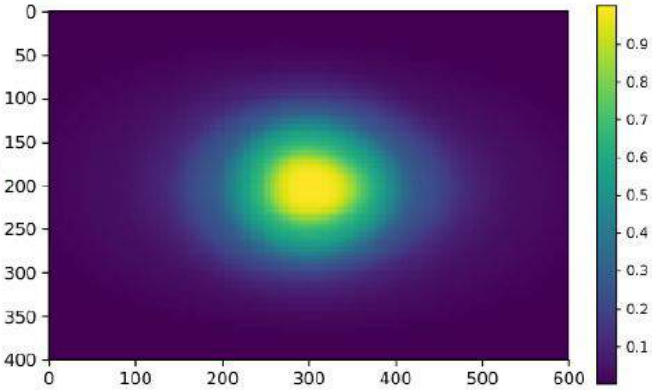
Shape model & prior

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

$$\text{with} \quad f_j(\boldsymbol{r}(i)) = \frac{1}{\sigma_{i,j}\sqrt{2\pi}} \exp\left(-\frac{(\boldsymbol{r}(i) - \mu_{i,j})^2}{2\sigma_{i,j}^2}\right) \quad \text{and} \quad \sum_{j}^{M} w_j = 1$$



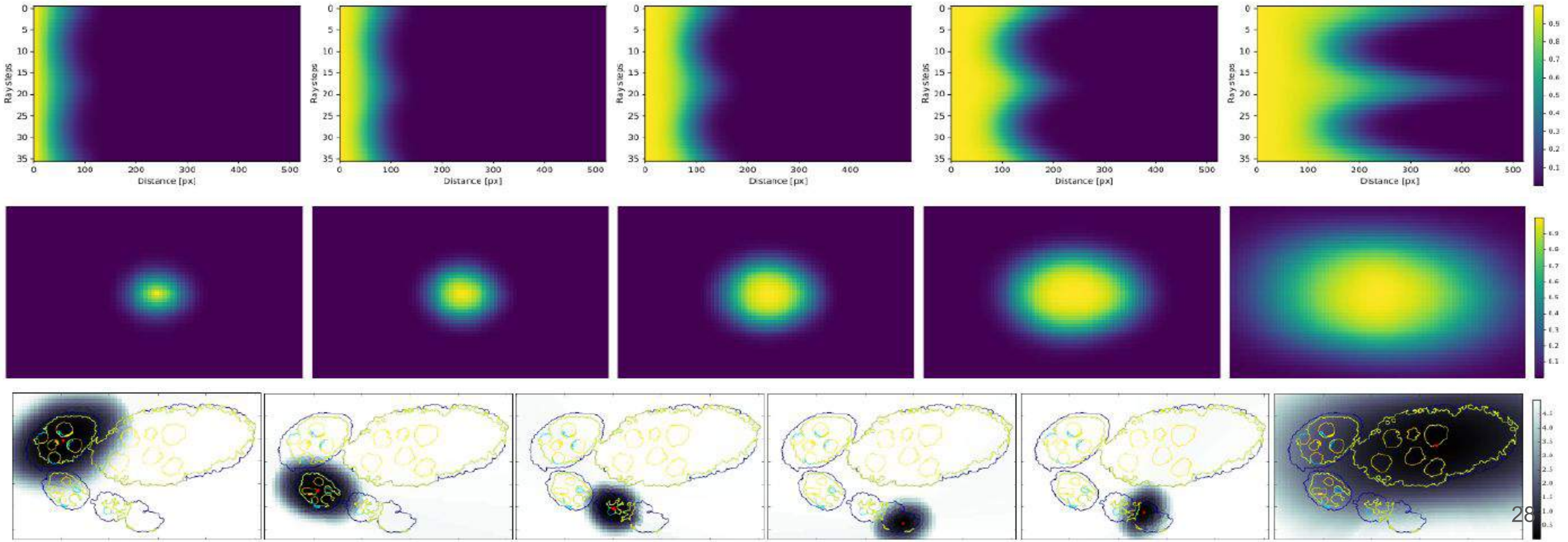




$$q(s, \boldsymbol{m}_k) = \int_{\delta}^{\infty} \rho(r)\,\mathrm{d}r = 1 - \int_{0}^{\delta} \rho(r)\,\mathrm{d}r$$

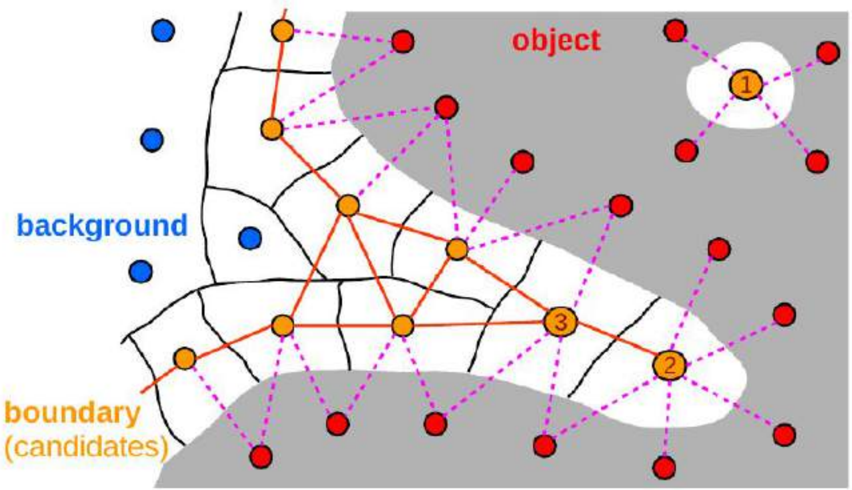
Mixture model

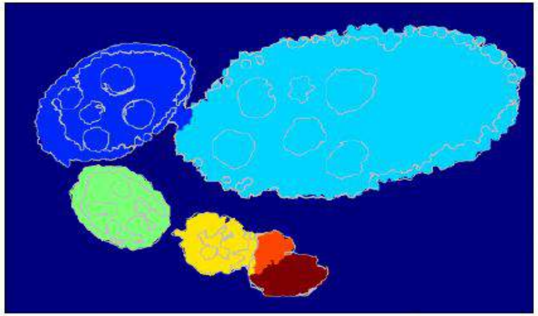
$$P_m(g(s) = k \mid \boldsymbol{M}) = \begin{cases} q(s, \boldsymbol{m}_k) & \text{for } k > 0 \\ \prod_l (1 - q(s, \boldsymbol{m}_l)) & \text{for } k = 0 \end{cases}$$

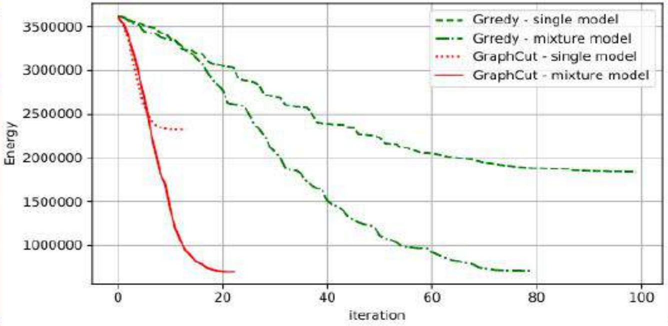


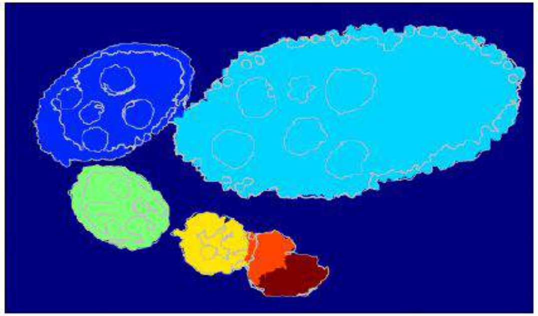
Region growing - optimisation

- Greedy
- Multi-class Graph Cut
- Binary Graph Cut
- Object swapping



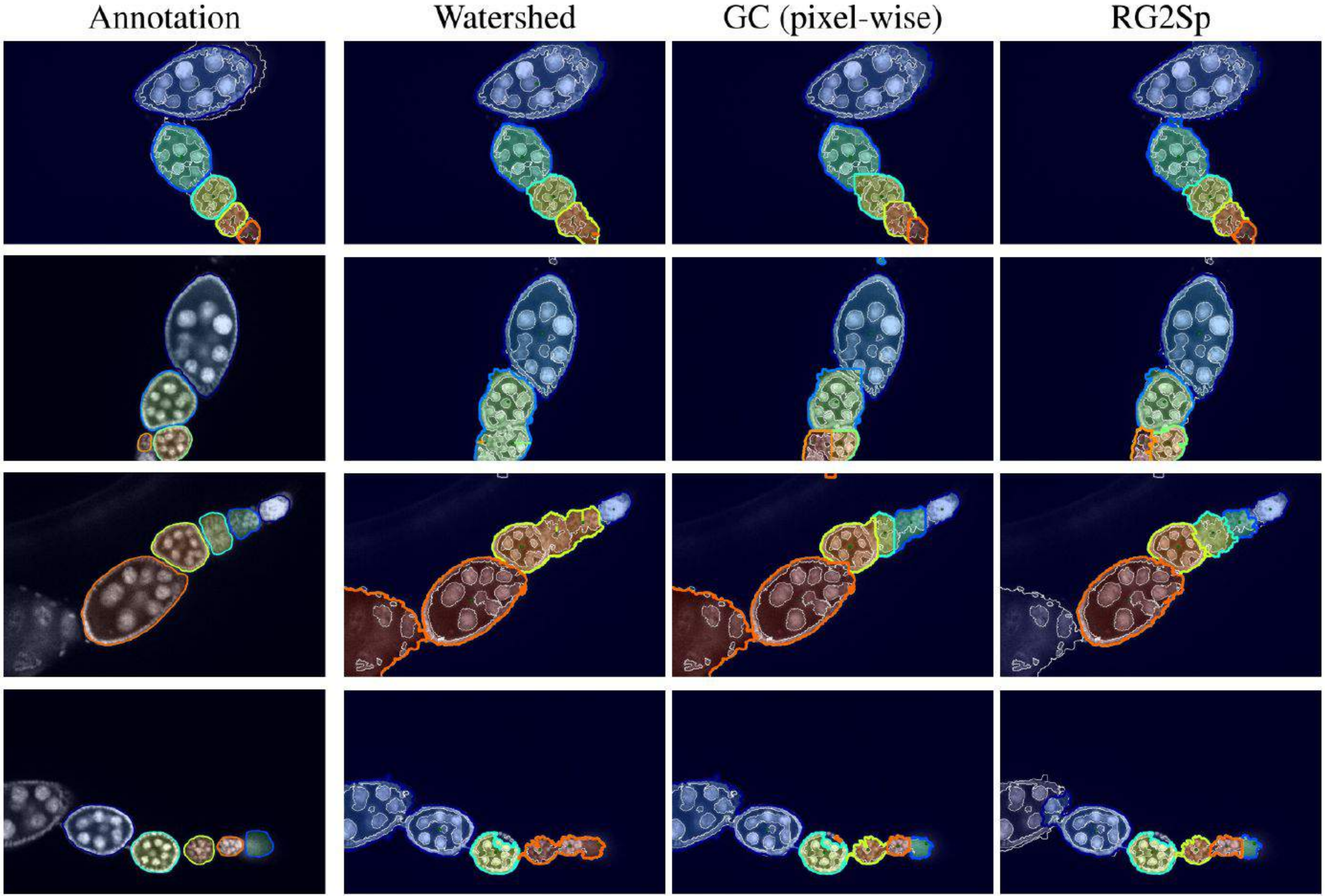






Result compare to SOA

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


Annotation
Watershed
GC (pixel-wise)
RG2Sp

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
  - ...