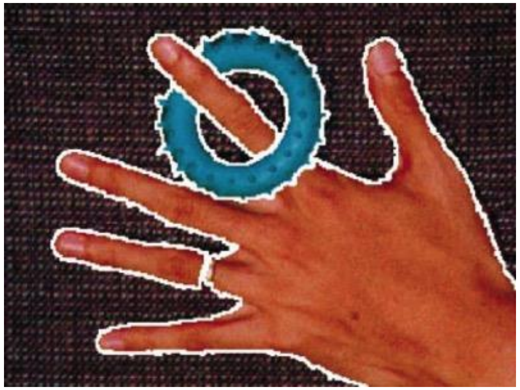
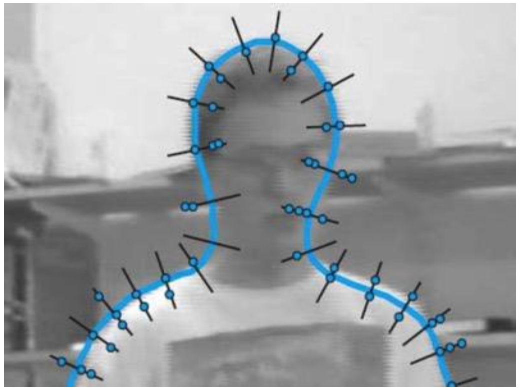




COMP 9517 Computer Vision

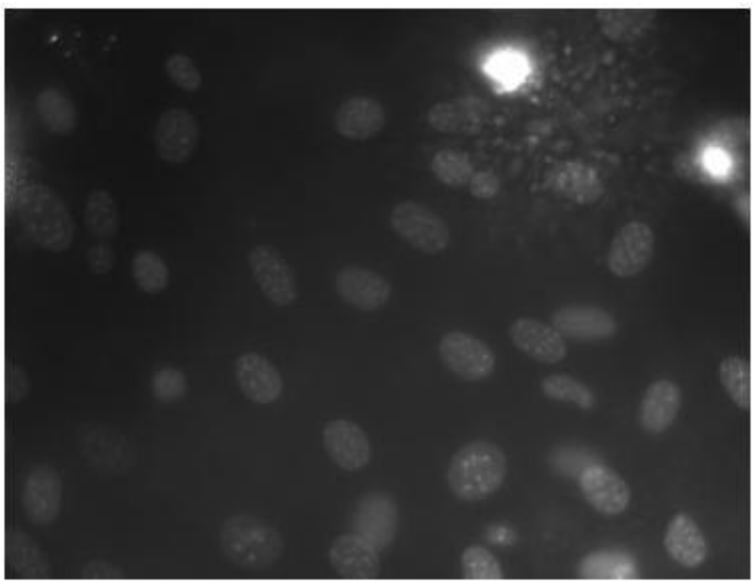
Segmentation – part 2

Case Studies

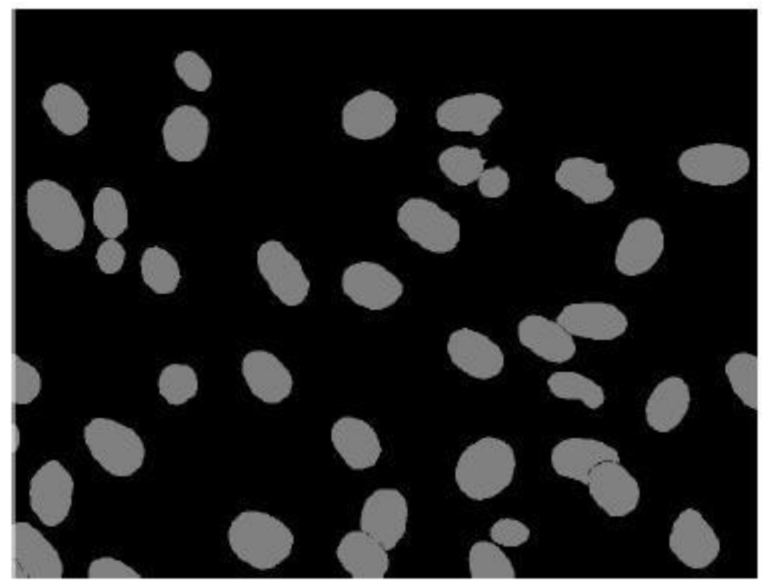
- Cell nuclei segmentation
- Overlapping cell segmentation
- Object segmentation

Cell Nuclei Segmentation

- Challenges
  - Varying characteristics of cell nuclei
  - Clustered regions
  - Noisy background



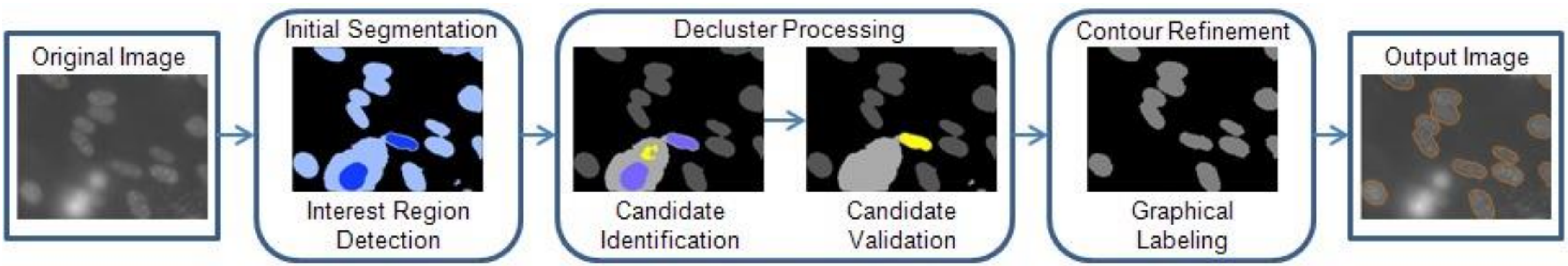
Image



Ground truth

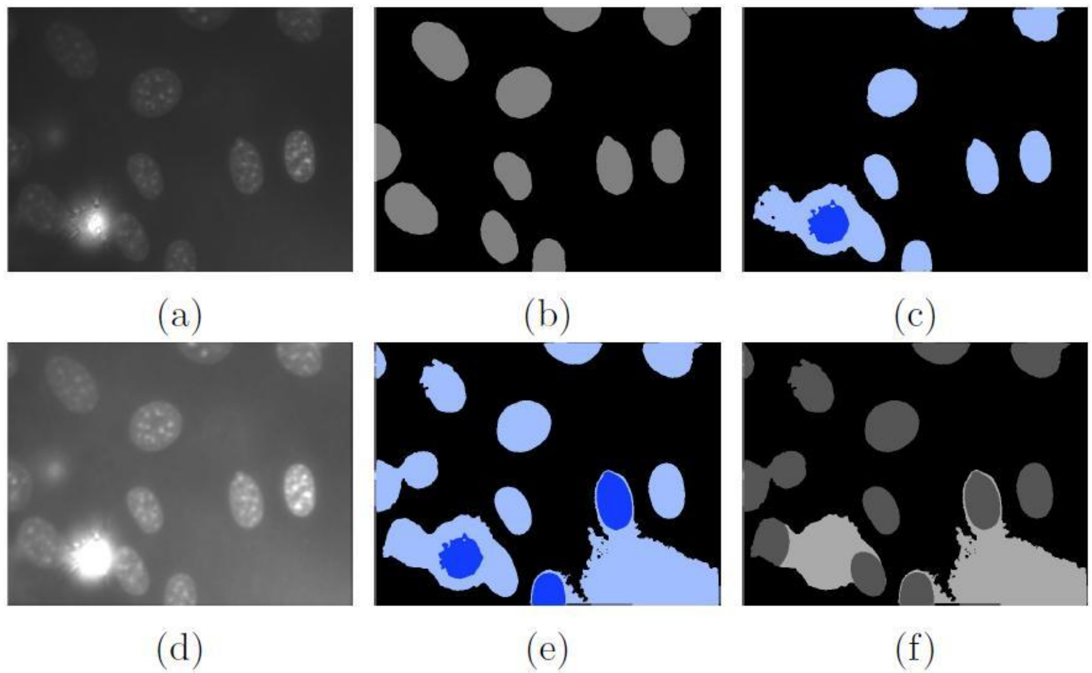
Cell Nuclei Segmentation

- A multi-stage segmentation approach
  - Initial segmentation
  - Decluster processing
  - Contour refinement



Cell Nuclei Segmentation

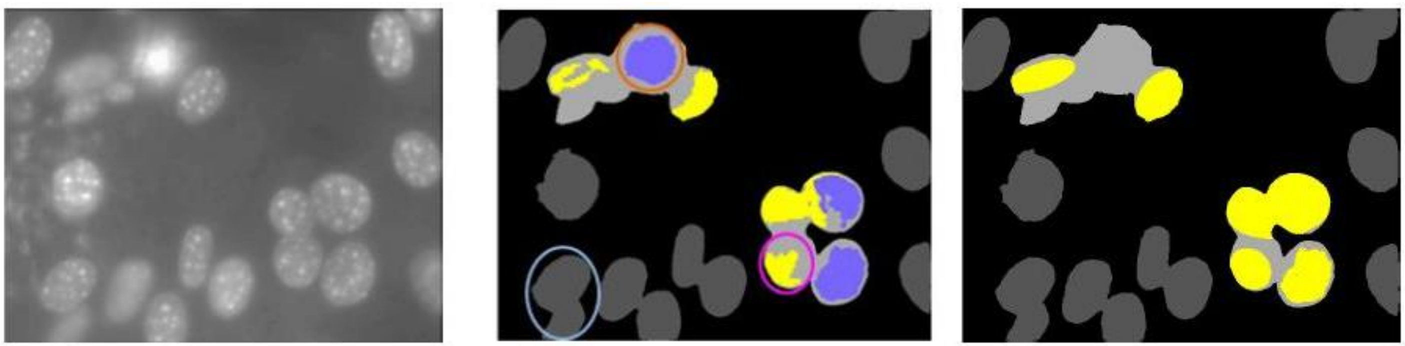
- Stage 1: initial segmentation



(a) The original image. (b) The segmentation ground truth. (c) The interest regions detected via MSER, and darker blue denotes upper-level regions. (d) The image after iterative contrast enhancement. (e) The interest regions detected via MSER and iterative contrast enhancement. After the initial segmentation, decluster processing is performed, with outputs shown in (f) and dark gray indicating the detected cell nuclei.

Cell Nuclei Segmentation

- Stage 2: decluster processing
  - SIFT-based classification for candidate identification
  - Kernel density estimation for candidate validation

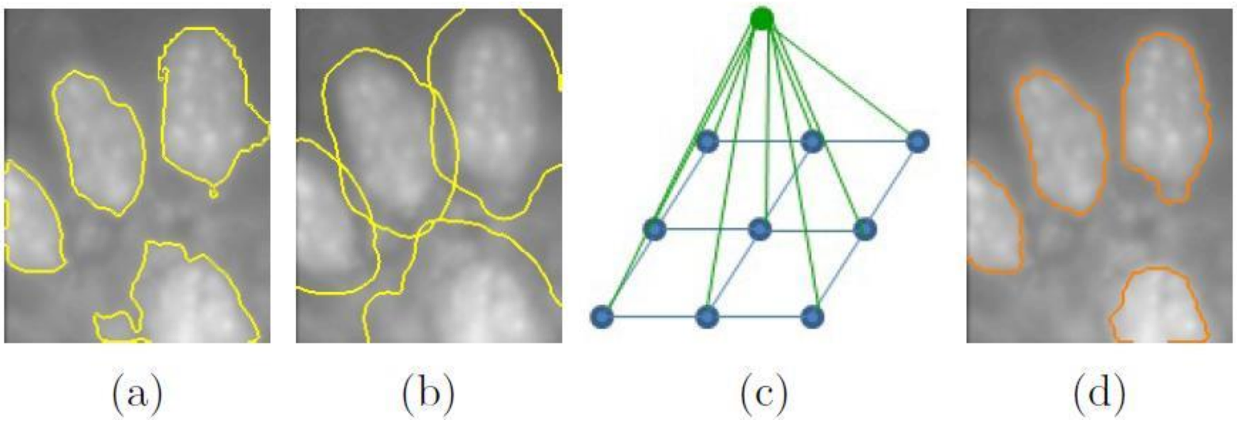


(a) (b) (c)

(a) The example image (after iterative enhancement). (b) Newly identified candidate regions are shown in yellow, with purple indicating the ones detected during initial segmentation, and both gray and purple denoting the reference regions; here to illustrate the probability inference, the light blue circle highlights one reference region, and pink and orange circles indicate two candidate regions. (c) The candidates validated shown as yellow.

Cell Nuclei Segmentation

- Stage 3: contour refinement
  - using Conditional Random Field (CRF)



(a) Segmentation output after the decluster processing shown with yellow contours. (b) Dilated cells indicated with yellow contours. (c) Visualization of the graphical model, with blue nodes representing the pixels and green node a global term, and the blue and green edges denoting the pairwise relationships. (d) Results of contour refinement with orange contours.

Cell Nuclei Segmentation

- Segmentation results

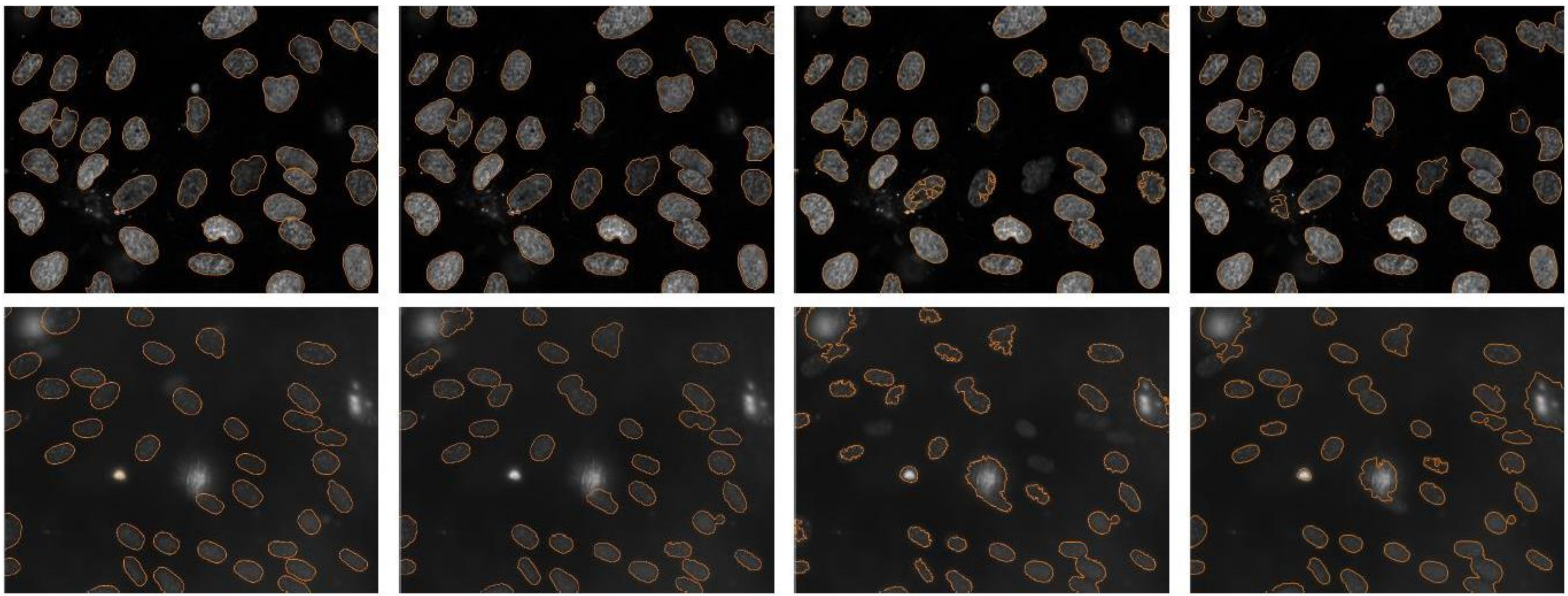
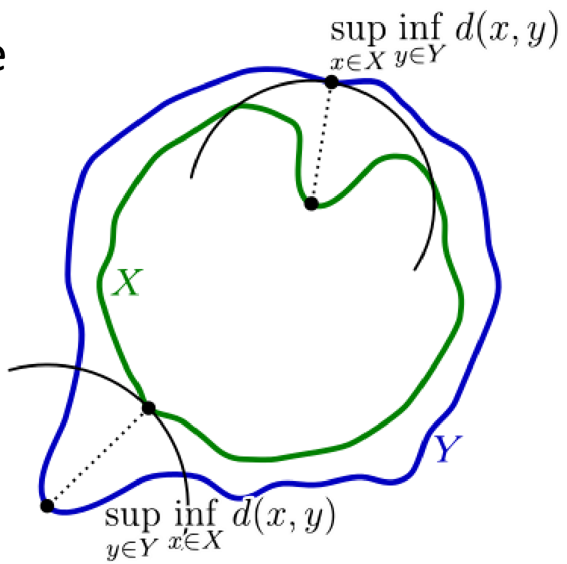


Image and ground truth Three-stage approach Otsu thresholding Level-set

Cell Nuclei Segmentation

- Commonly used evaluation metrics
  - Pixel-level evaluation metrics
    - Dice coefficient $$Dice(X,Y) = \frac{2|X \cap Y|}{|X| + |Y|}$$
    - Hausdorff distance



Cell Nuclei Segmentation

- Commonly used evaluation metrics
  - Object-level evaluation metrics
    - Recall, precision, accuracy

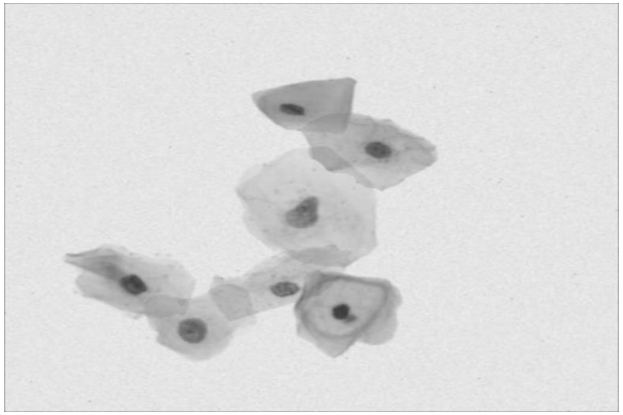
$$
\begin{aligned}
R &= TP/(TP+FN) \\
P &= TP/(TP+FP) \\
A &= TP/(TP+FN+FP)
\end{aligned}
$$

    - True positive (TP) when overlap ratio between detection and ground truth is at least 0.5

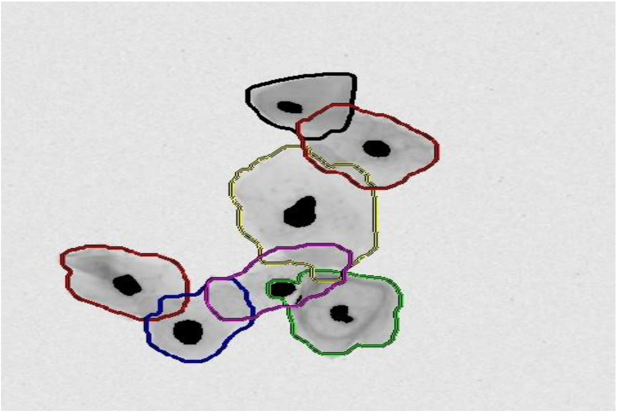
$$R(O_d) = |O_d \cap O_{gt}|/|O_d \cup O_{gt}|$$

Overlapping Cell Segmentation

- Challenges
  - Overlapping cytoplasm
  - Unclear boundaries between cells

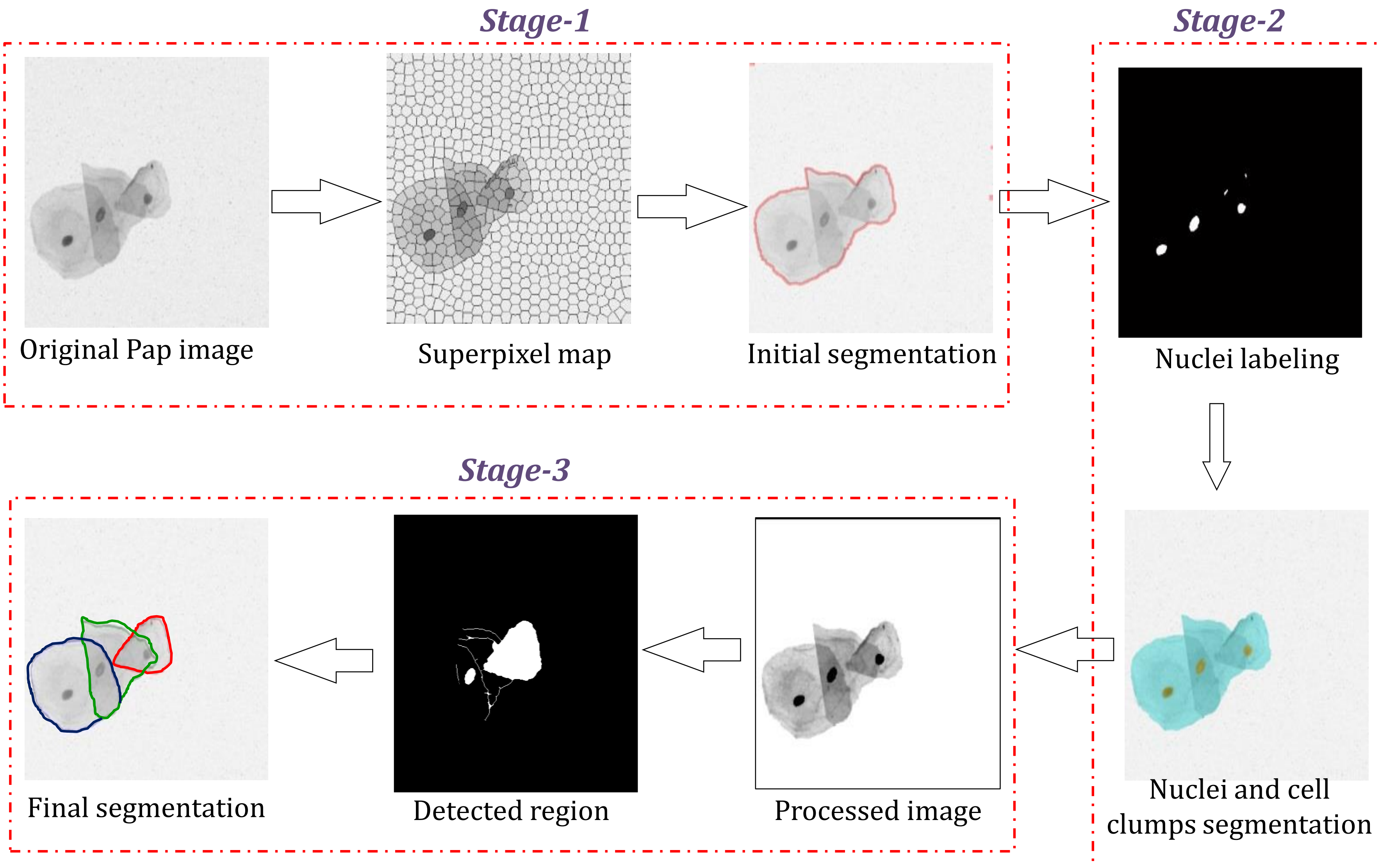


Image



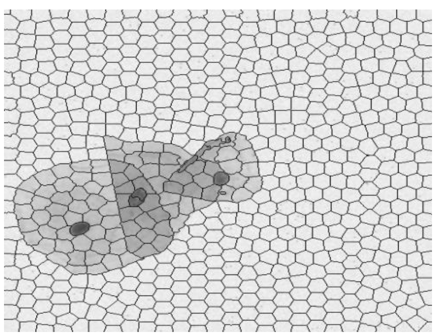
Ground truth

Overlapping Cell Segmentation

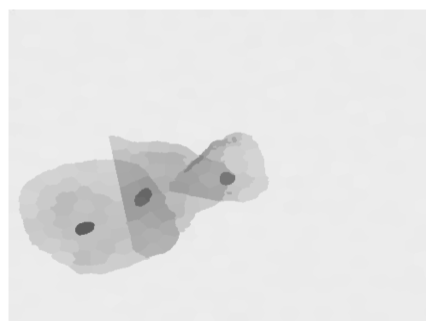


Overlapping Cell Segmentation

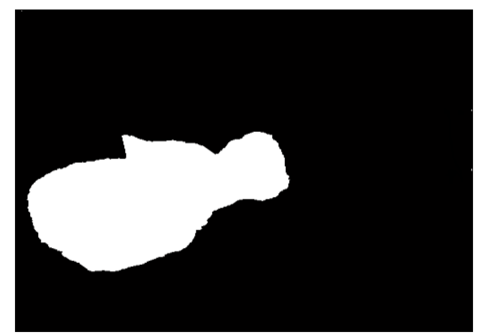
- Stage 1: initial cluster segmentation
  - Superpixel general with SLIC
  - Refinement with mean values
  - Segmentation using adaptive thresholding



SLIC map



Refined superpixel map

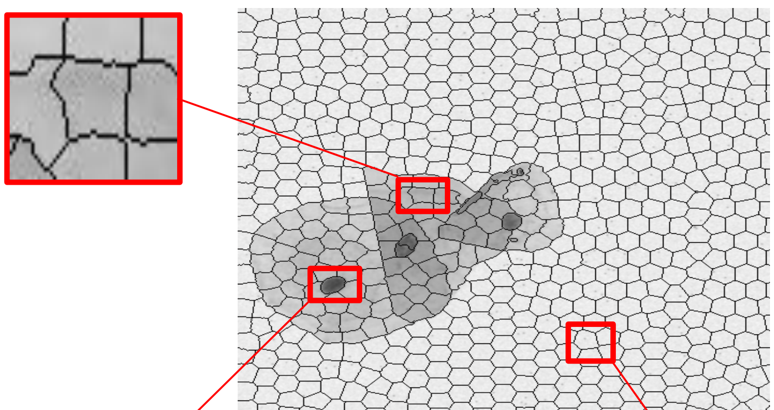


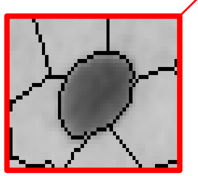
Initial cellular cluster segmentation

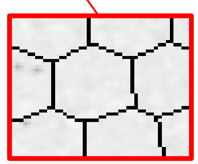
Overlapping Cell Segmentation

- Stage 2: nuclei segmentation

Step 1: Local feature extraction



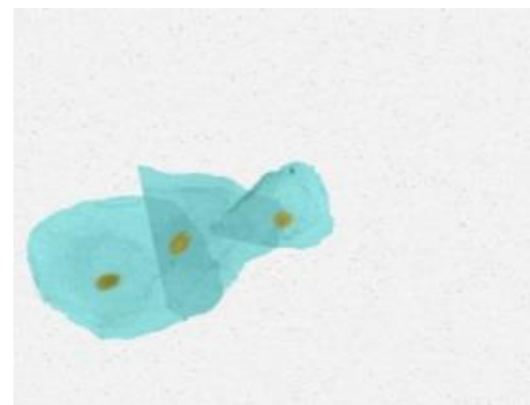




<u>Nuclei features:</u>

- Lower intensity.
- Homogenous texture.
- Clear boundaries.
- Circular shape.

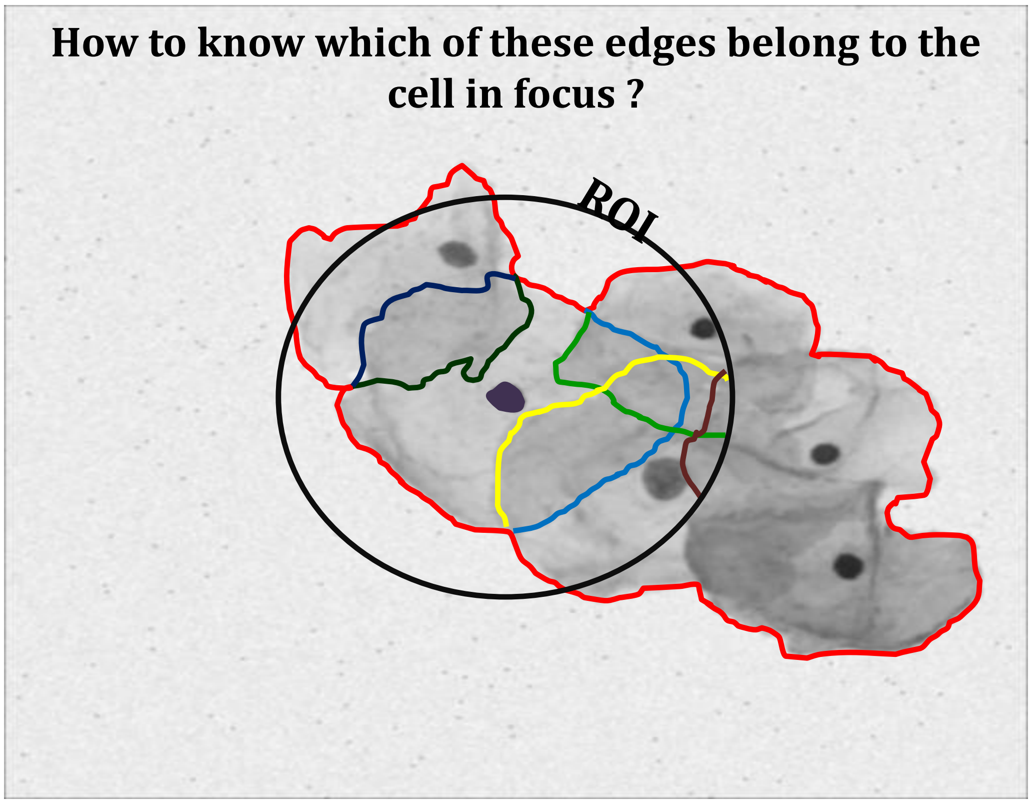
Step 2: Support Vector Machine (SVM)



nuclei segmentation

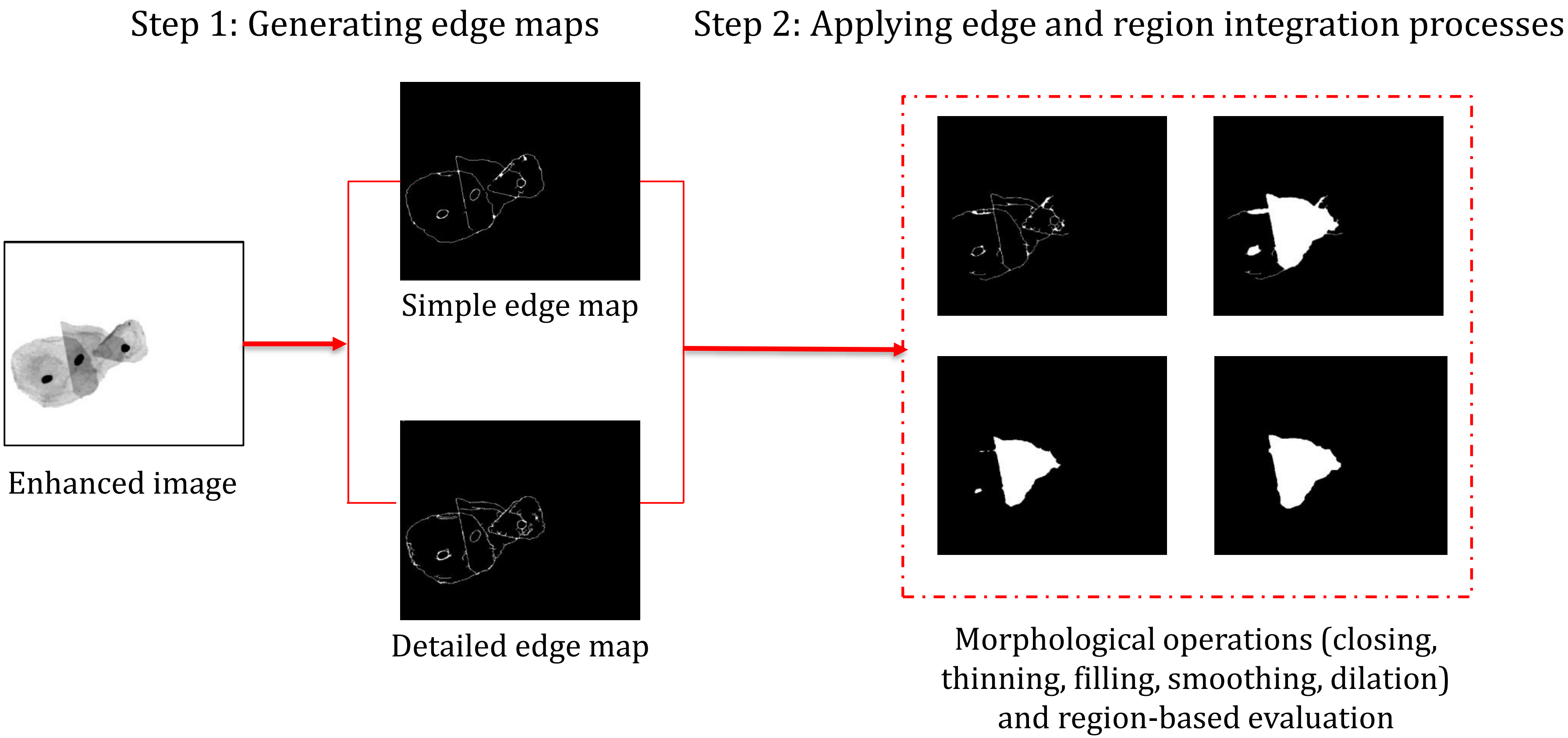
Overlapping Cell Segmentation

- Stage 3: cytoplasm segmentation



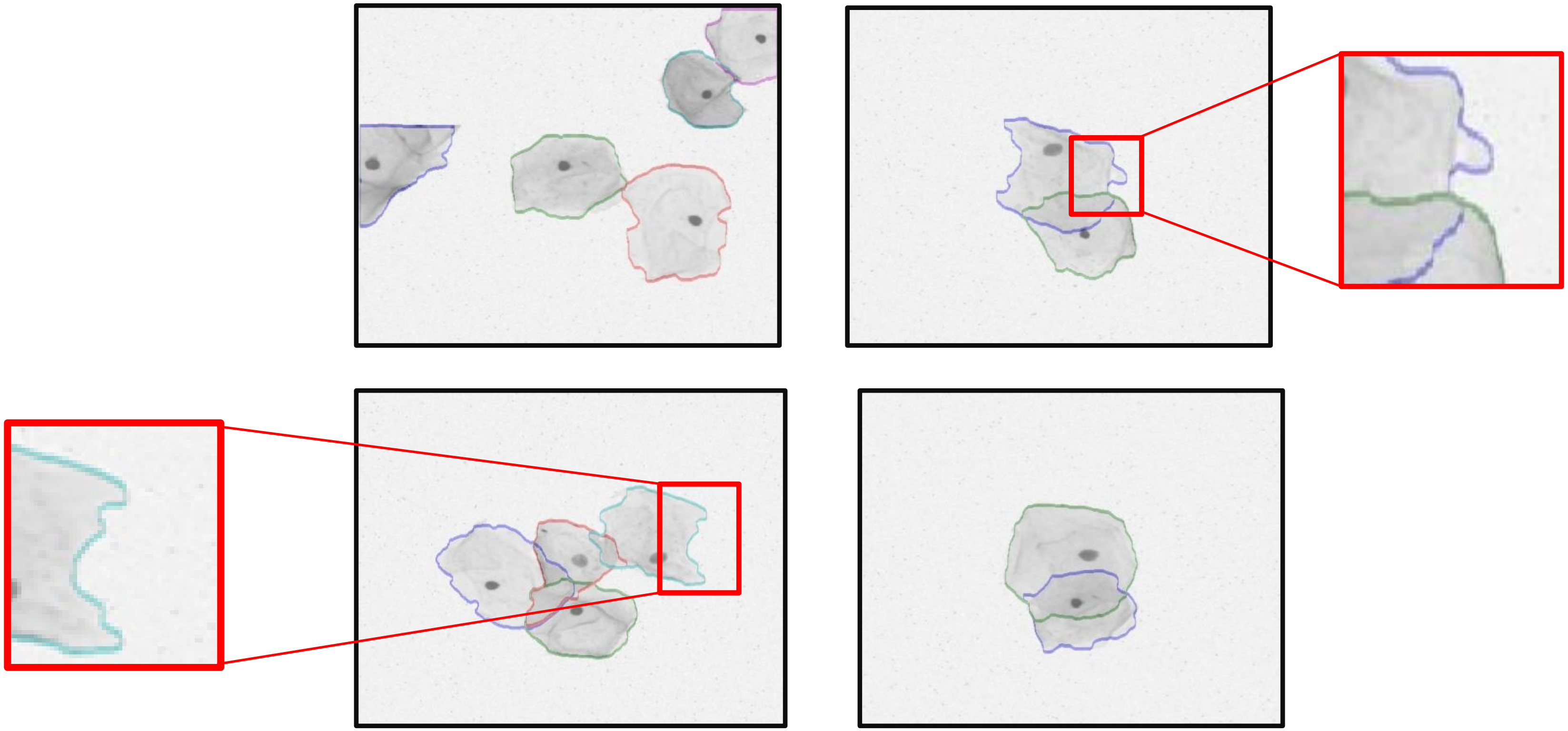
Overlapping Cell Segmentation

- Stage 3: cytoplasm segmentation
  - Lots of thresholding and morphological processing



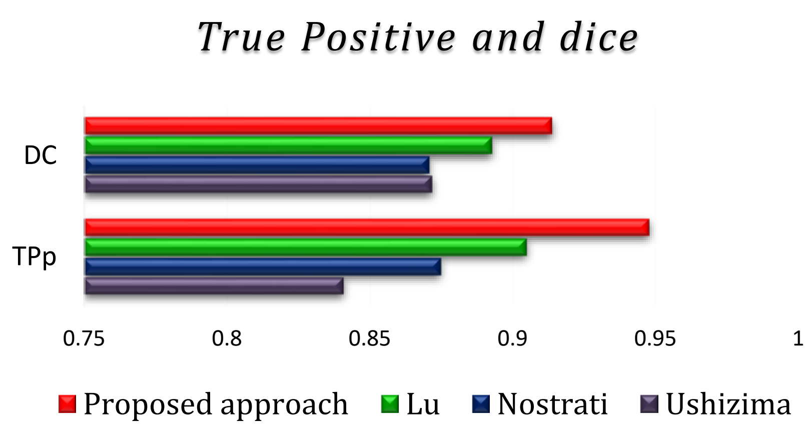
Overlapping Cell Segmentation

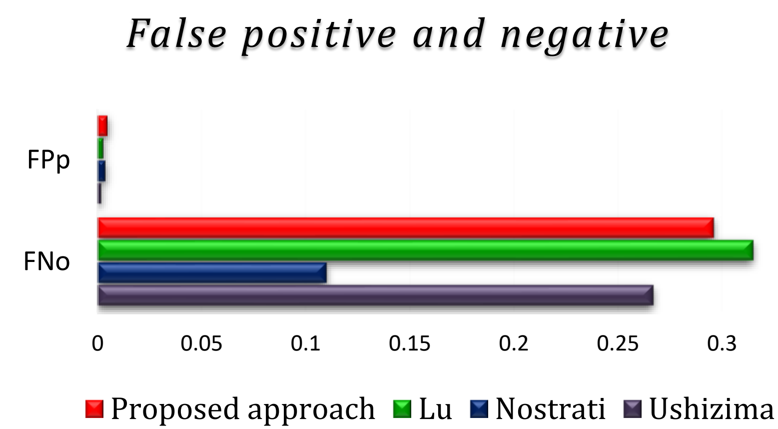
- Results



Overlapping Cell Segmentation

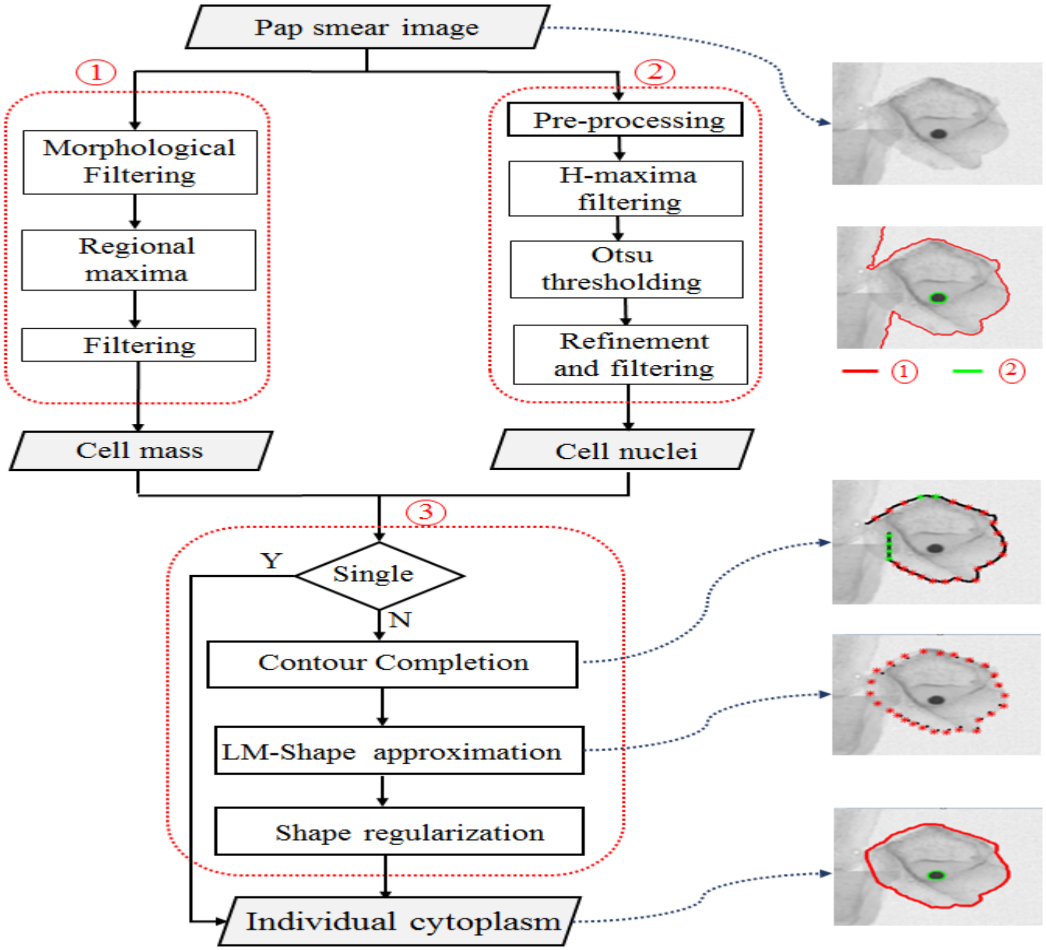
- Quantitative results





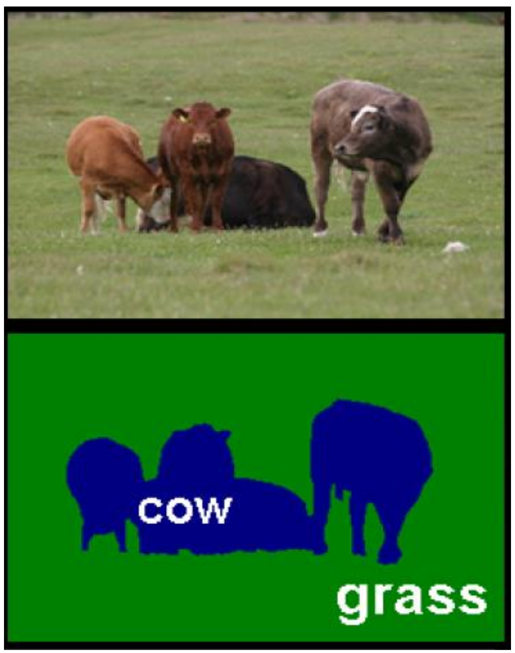
Overlapping Cell Segmentation

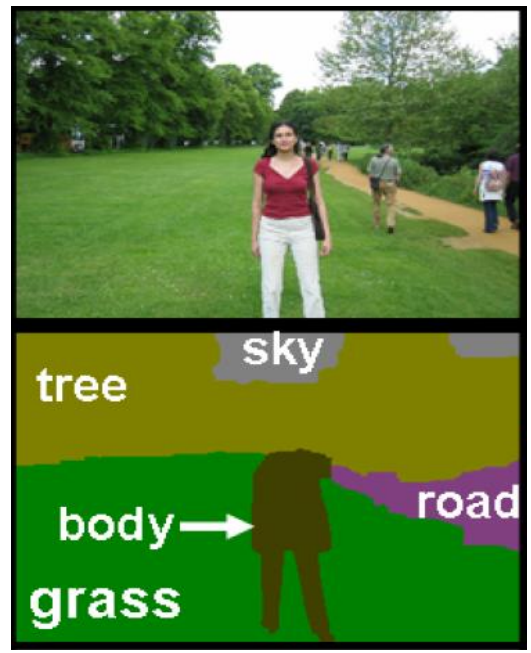
- Another approach



Object Segmentation

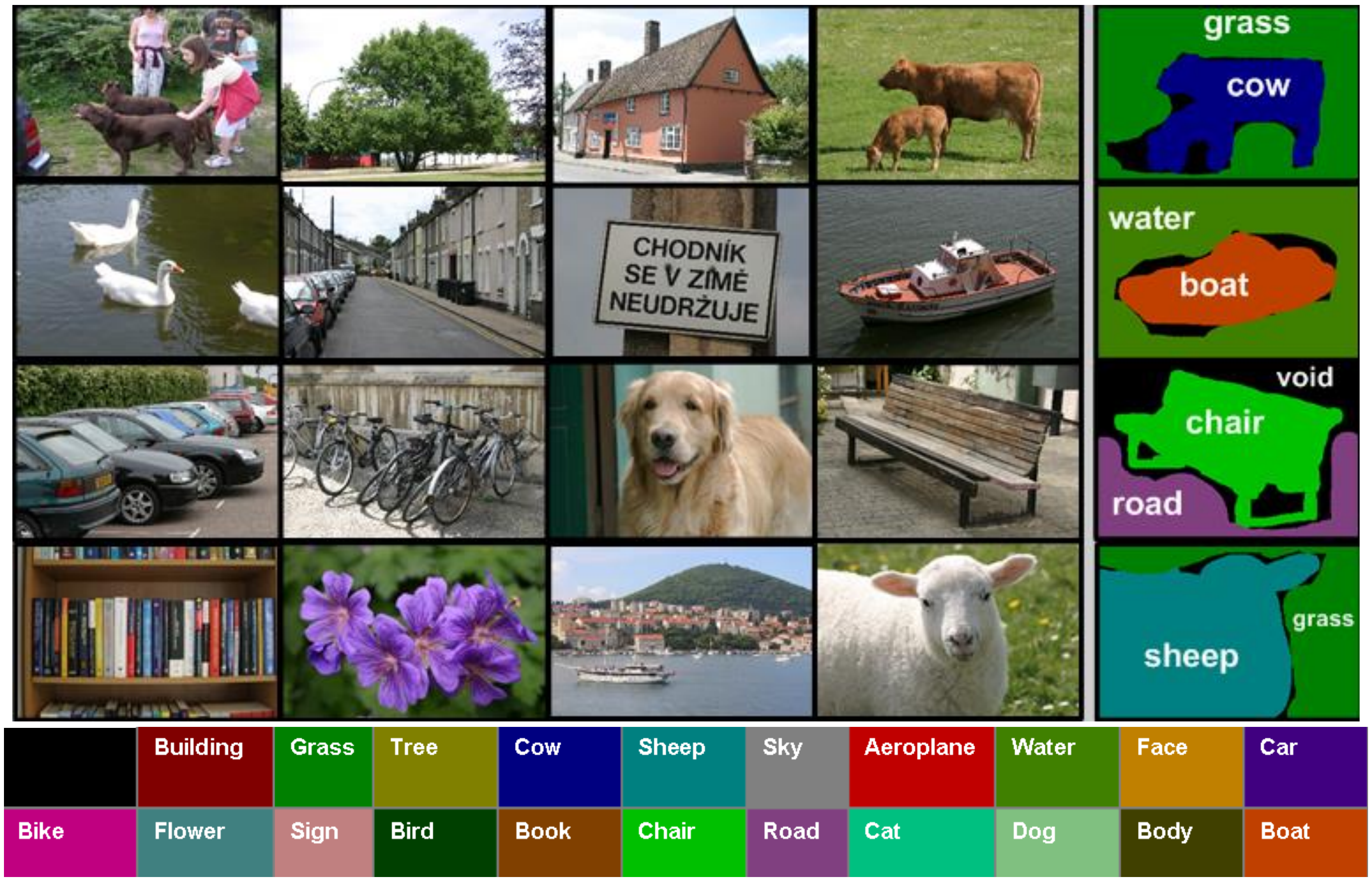
- *TextonBoost*: Joint Appearance, Shape and Context Modeling for Multi-Class Object Recognition and Segmentation
  - Simultaneous recognition and segmentation of objects





Object Segmentation

- Image database
  - MSRC 21-class object recognition database



Object Segmentation

- Successes using sparse features, e.g.

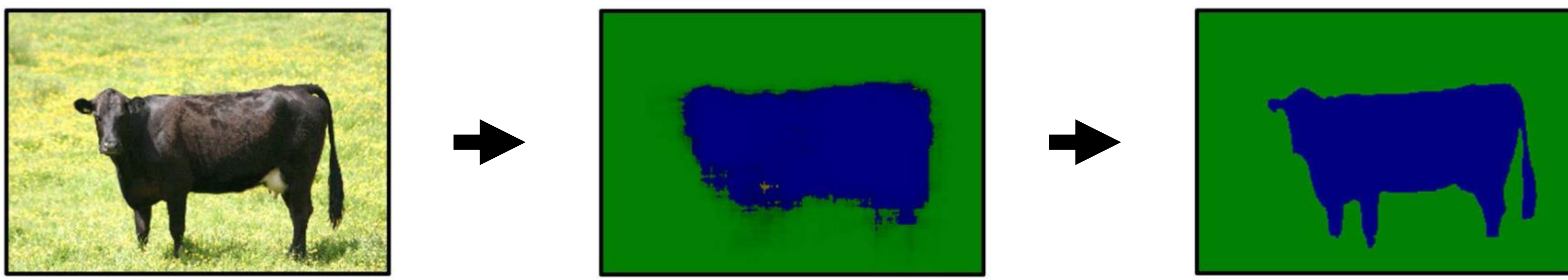
  [Sivic *et al.* ICCV 2005], [Fergus *et al.* ICCV 2005], [Leibe *et al.* CVPR 2005]
- But…
  - do not explain whole image
  - cannot cope well with all object classes

- TextonBoost use *dense* features
  - 'shape filters'
  - local texture-based image descriptions

- Cope with
  - textured and untextured objects, occlusions, whilst retaining high efficiency

Object Segmentation

- Overall process
  - Feature extraction + Joint boost classification + CRF

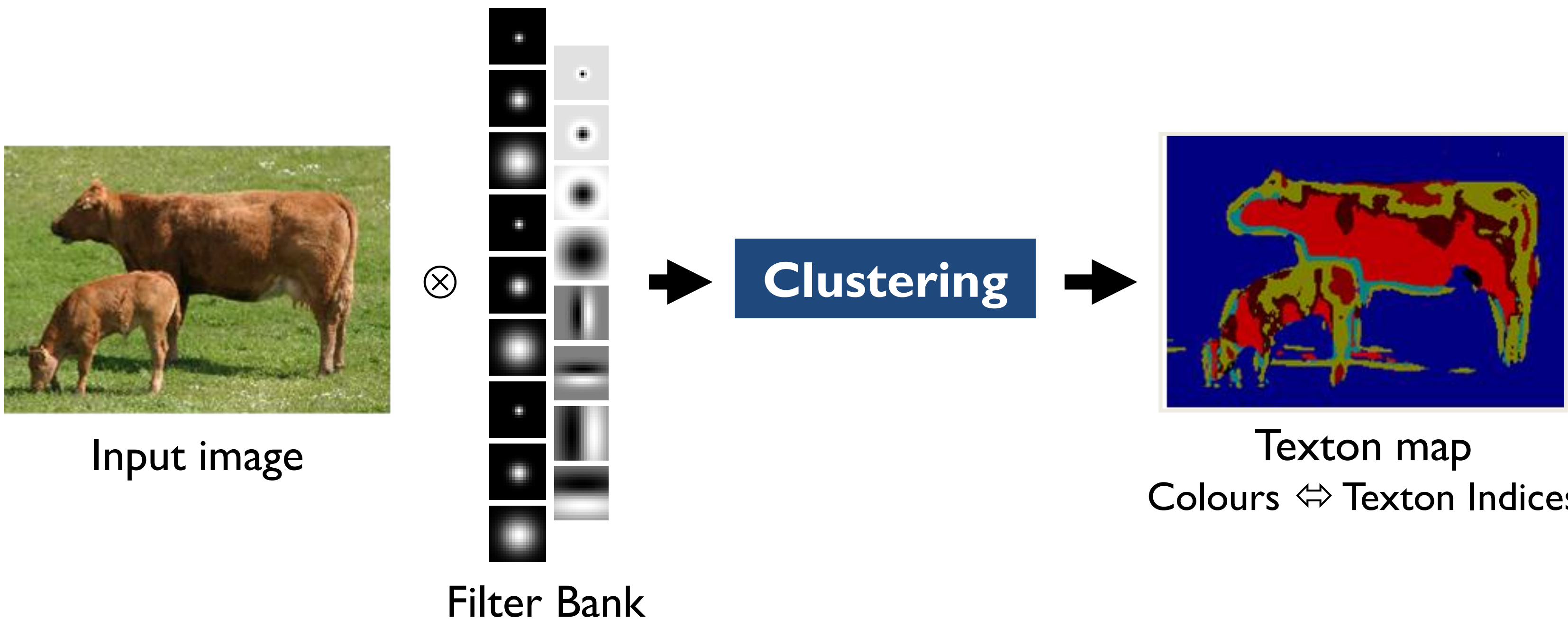


Joint boost classification   CRF

Features: **shape-texture**, colour, location

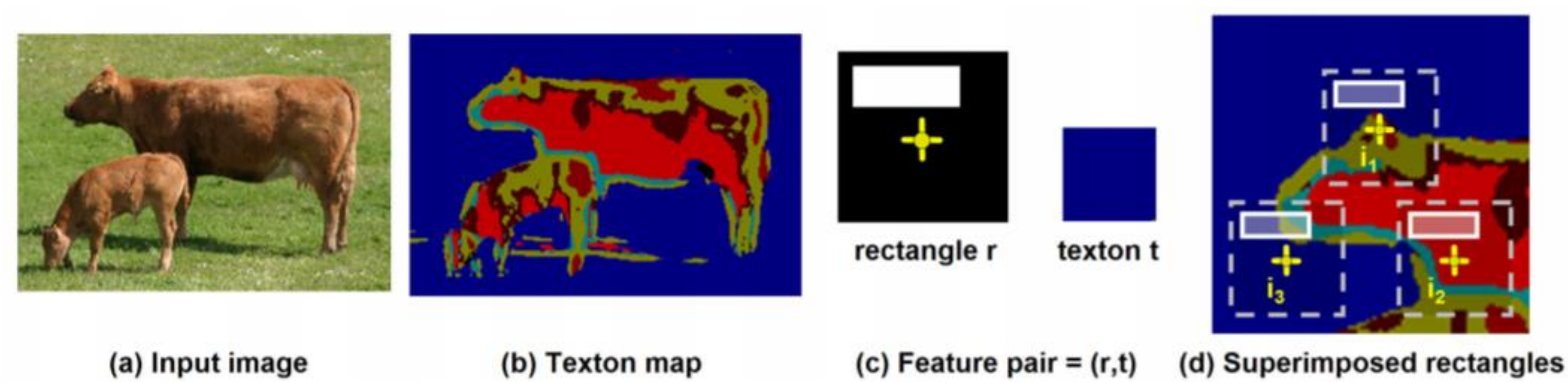
Object Segmentation

- Textons
  - Generated using bag-of-words
  - Compact and efficient characterisation of local texture



Object Segmentation

- Shape filter response
  - count of the instances of that texton under the rectangular mark r



Shape filter responses and appearance context. (a, b) An image and its corresponding texton map (colors map uniquely to texton indices). (c) A rectangle mask r (white) is offset from the center (yellow cross), and paired with a texton index t which here maps to the blue color. (d) As an example, the feature response v(i, r, t) is calculated at three positions in the texton map (zoomed). If A is the area of r, then in this example v(i1, r, t) ≈ A, v(i2, r, t) ≈ 0, and v(i3, r, t) ≈ A/2.

Object Segmentation

- Classification
  - Joint Boost algorithm
    - iteratively combines many shape filters
    - builds multi-class logistic classifier
  - Resulting combination exploits:

Shape

Texture

Context (!)

Object Segmentation

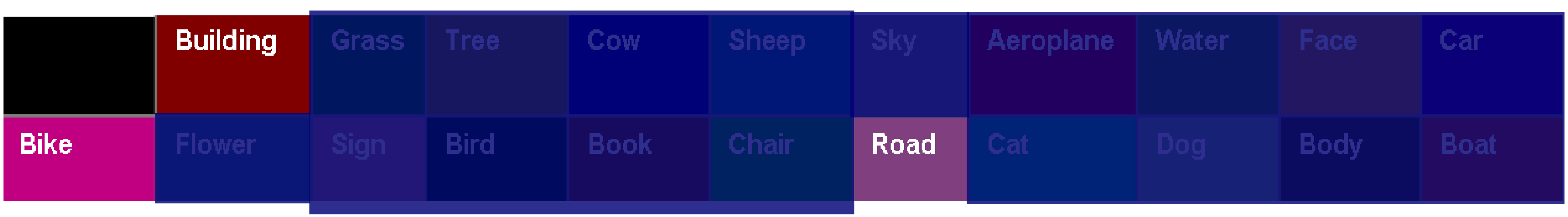
- Classification

30 rounds 1000 rounds 2000 rounds

input image

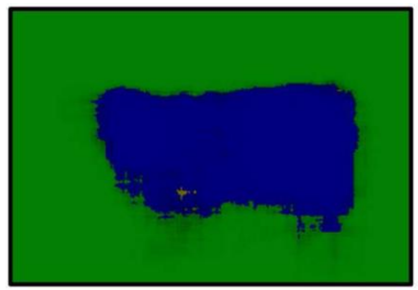
inferred segmentation
colour = most likely label

confidence
white = high entropy
black = low entropy

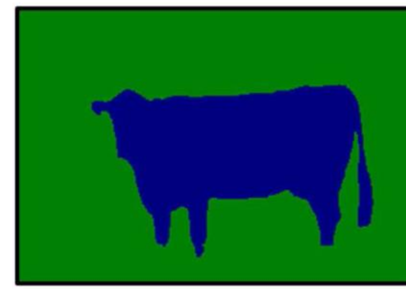


Object Segmentation

- Overall process
  - Shape-texture, colour, location + Joint boost + CRF



Joint boost classification



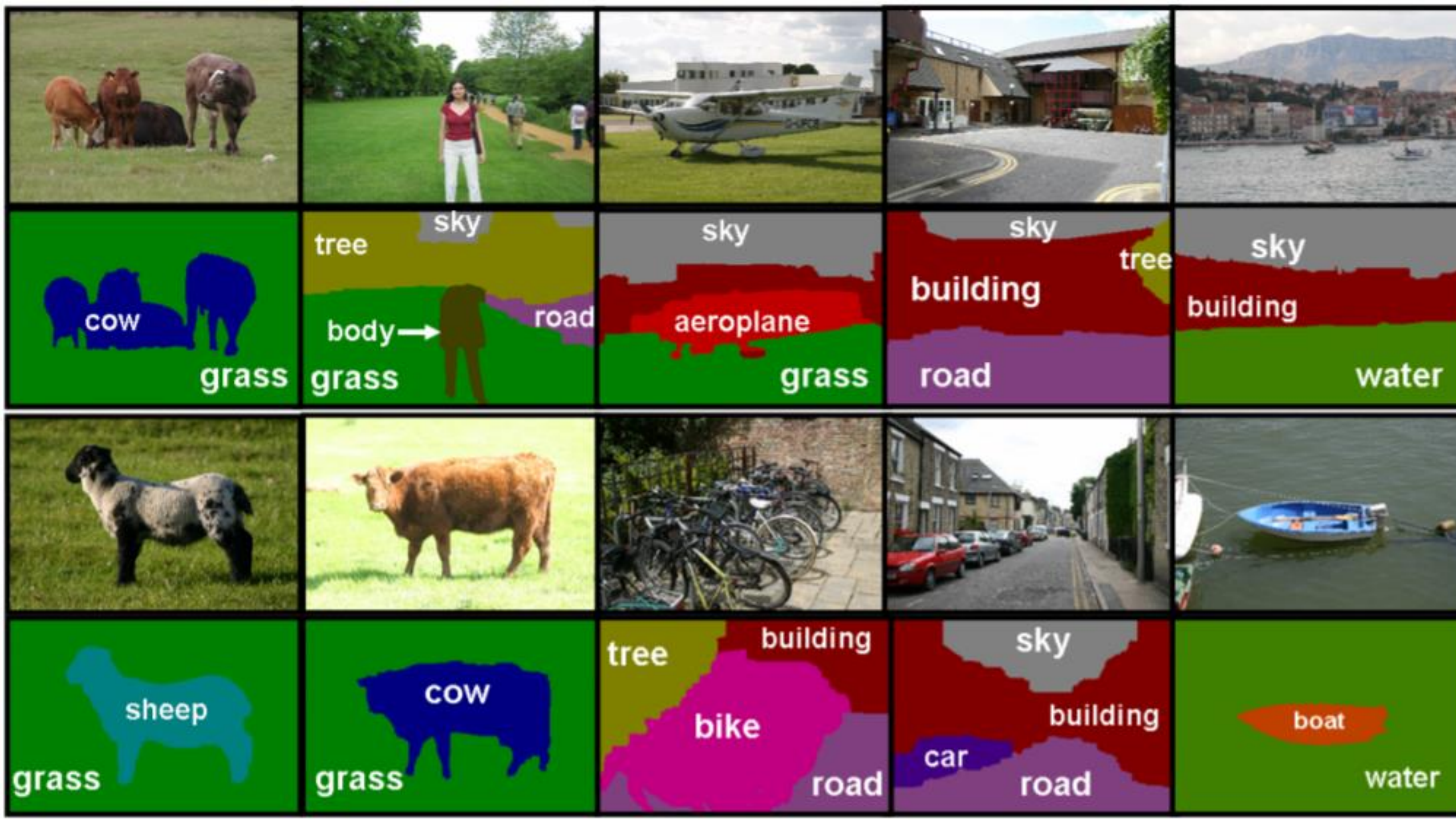
CRF

$$\log P(\mathbf{c}|\mathbf{x},\boldsymbol{\theta}) = \sum_i \overbrace{\psi_i(c_i,\mathbf{x};\boldsymbol{\theta}_\psi)}^{\text{shape-texture}} + \overbrace{\pi(c_i,\mathbf{x}_i;\boldsymbol{\theta}_\pi)}^{\text{color}} + \overbrace{\lambda(c_i,i;\boldsymbol{\theta}_\lambda)}^{\text{location}}$$

$$+ \sum_{(i,j)\in\mathcal{E}} \overbrace{\phi(c_i,c_j,\mathbf{g}_{ij}(\mathbf{x});\boldsymbol{\theta}_\phi)}^{\text{edge}} - \log Z(\boldsymbol{\theta},\mathbf{x})$$

Object Segmentation

- Results



Object Segmentation

- Results
  - Examples showing incorrect results

Object Segmentation

- Quantitative results

True class \ Inferred class	building	grass	tree	cow	sheep	sky	aeroplane	water	face	car	bike	flower	sign	bird	book	chair	road	cat	dog	body	boat
building	**61.6**	4.7	9.7	0.3		2.5	0.6	1.3	2.0	2.6	2.1		0.6	0.2	4.8		6.3	0.4		0.5	
grass	0.3	**97.6**	0.5								0.1									1.3	
tree	1.2	4.4	**86.3**	0.5		2.9	1.4	1.9	0.8	0.1							0.1		0.2	0.1	
cow		30.9	0.7	**58.3**				0.9	0.4			0.4			4.2					4.1	
sheep	16.5	25.5	4.8	1.9	**50.4**									0.6			0.2				
sky	3.4	0.2	1.1			**82.6**		7.5									5.2				
aeroplane	21.5	7.2				3.0	**59.6**	8.5													
water	8.7	7.5	1.5	0.2		4.5		**52.9**		0.7	4.9			0.2	4.2		14.1	0.4			
face	4.1		1.1						**73.5**	7.1					8.4			0.4	0.2	5.2	
car	10.1		1.7							**62.5**	3.8		5.9	0.2			15.7				
bike	9.3		1.3							1.0	**74.5**		2.5			3.9	5.9		1.6		
flower		6.6	19.3	3.0								**62.8**			7.3		1.0				
sign	31.5	0.2	11.5	2.1		0.5		6.0		1.5		2.5	**35.1**		3.6	2.7	0.8	0.3		1.8	
bird	16.9	18.4	9.8	6.3	8.9	1.8		9.4						**19.4**			4.6	4.5			
book	2.6		0.6						0.4			2.0			**91.9**					2.4	
chair	20.6	24.8	9.6	18.2		0.2					3.7				1.9	**15.4**	4.5		1.1		
road	5.0	1.1	0.7					3.4	0.3	0.7	0.6		0.1	0.1	1.1		**86.0**			0.7	
cat	5.0		1.1	8.9				0.2		2.0					0.6		28.4	**53.6**	0.2		
dog	29.0	2.2	12.9	7.1				9.7							8.1		11.7		**19.2**		
body	4.6	2.8	2.0	2.1	1.3	0.2			6.0	1.1					9.9		1.7	4.0	2.1	**62.1**	
boat	25.1		11.5			3.8		30.6		2.0	8.6		6.4	5.1			0.3				**6.6**

Fig. 8. Accuracy of segmentation for the 21-class database. Confusion matrix with percentages row-normalized. Overall pixel-wise accuracy 72.2%.

Summary

- Various segmentation methods can be combined in a multi-stage manner to improve the segmentation performance
- Feature representation is important in classification-based methods
- Segmentation performance is typically evaluated using Dice, Hausdorff distance, precision, recall, accuracy
- Cross-validation is important when machine learning is involved

References and Acknowledgements

- Some slides adopted from A. Tareef’s presentation on overlapping cell segmentation and J. Shotton’s presentation on TextonBoost