Object Detection in Microscopic Images

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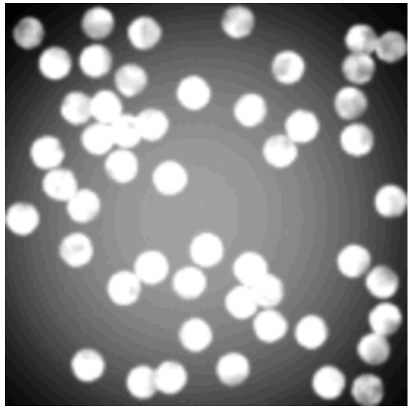
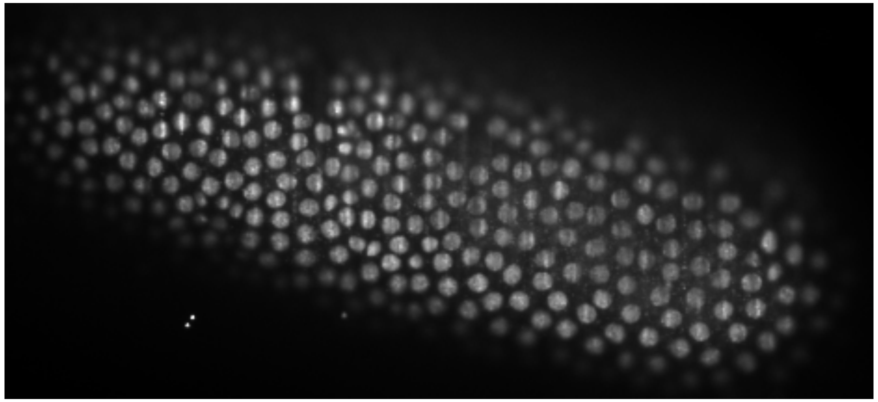
Multiple objects detection

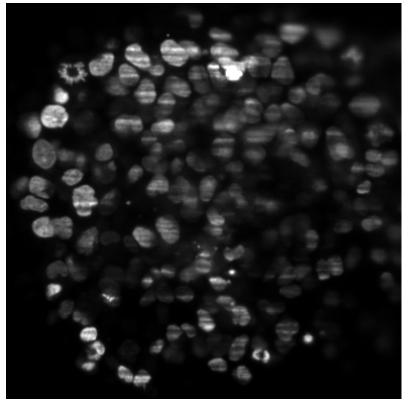
- Goal : evaluate a population, classification, shape statistics, initialize a tracking algorithm, …
- Automaticity : large sets of data, high throughput, expert independent
- Requirements: robustness, efficiency, ergonomic

Examples

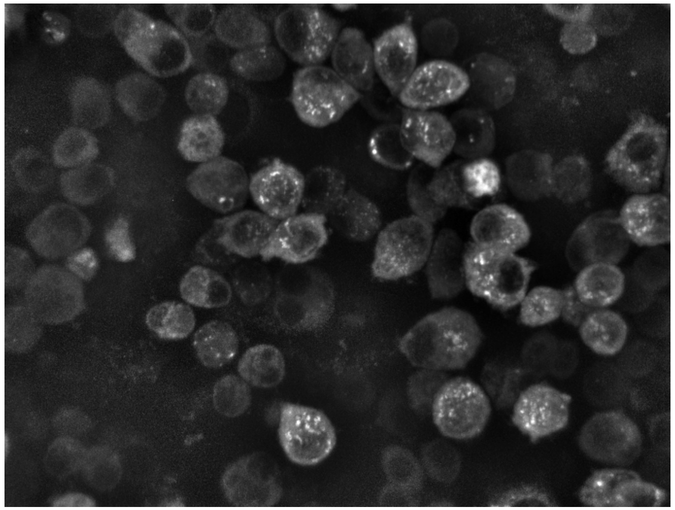


- Cells :





- Vesicles :



The ImageJ (Fiji) approach

- https://imagej.net/Particle_Analysis

1 – Threshold : manual or automatic

2 – Separation using watershed

3 – Particles selection (« particle analyzer »)

1 - Threshold

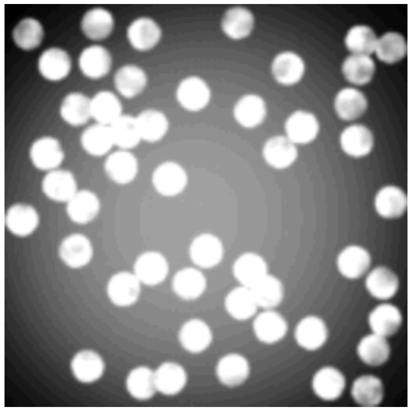
$$T(x,y) = \begin{cases} 1 & \text{if } I(x,y) \geq t \\ 0 & \text{otherwise} \end{cases}$$

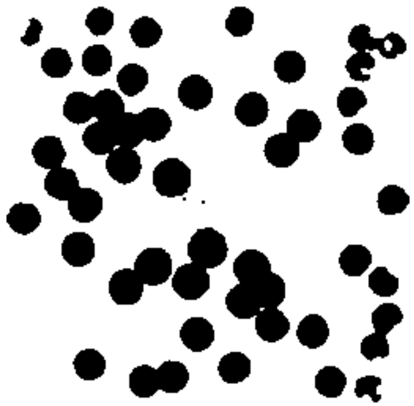
1 – Threshold (Automatic)

- Numerous techniques

- Otsu : minimum of intra-class variance

$$\operatorname{argmin}\left\{\omega_1(t)\sigma_1^2(t)+\omega_2(t)\sigma_2^2(t)\right\}$$





2 - Watershed

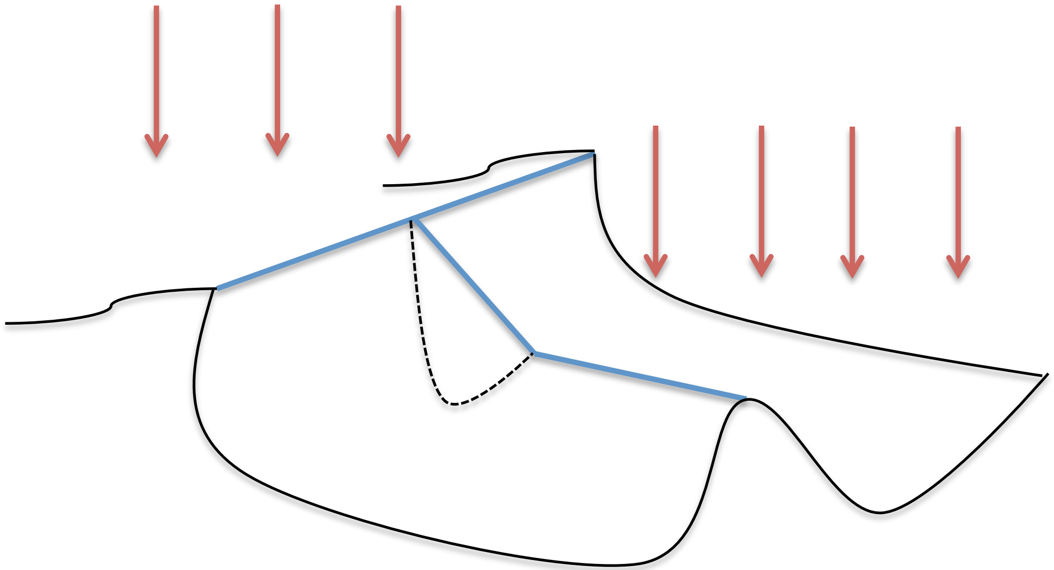
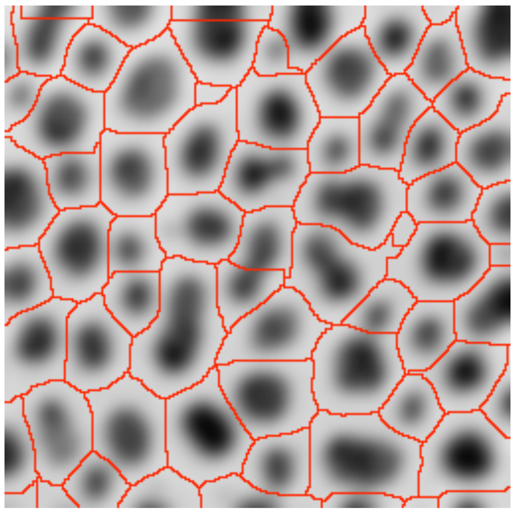
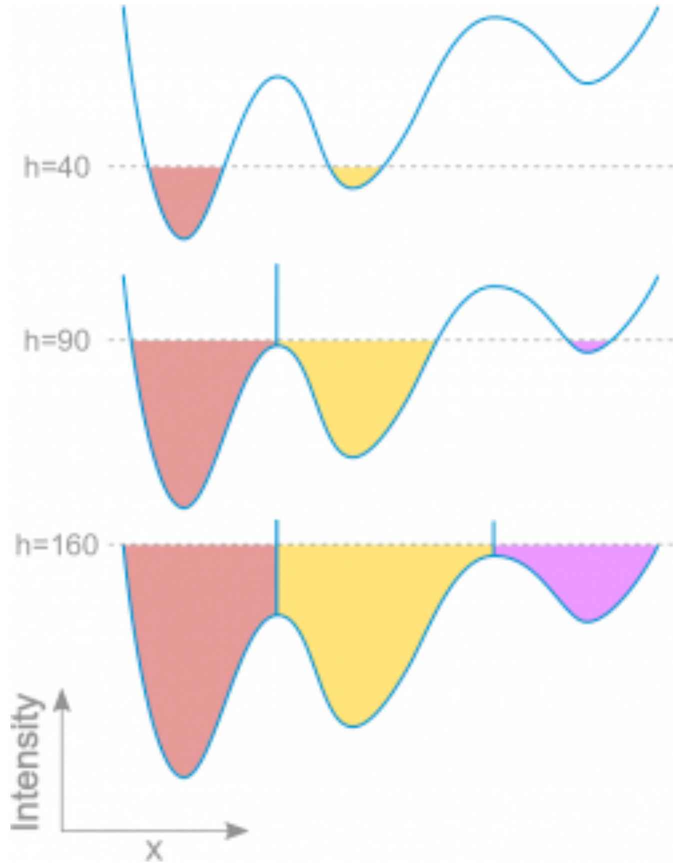


Image : topographical surface

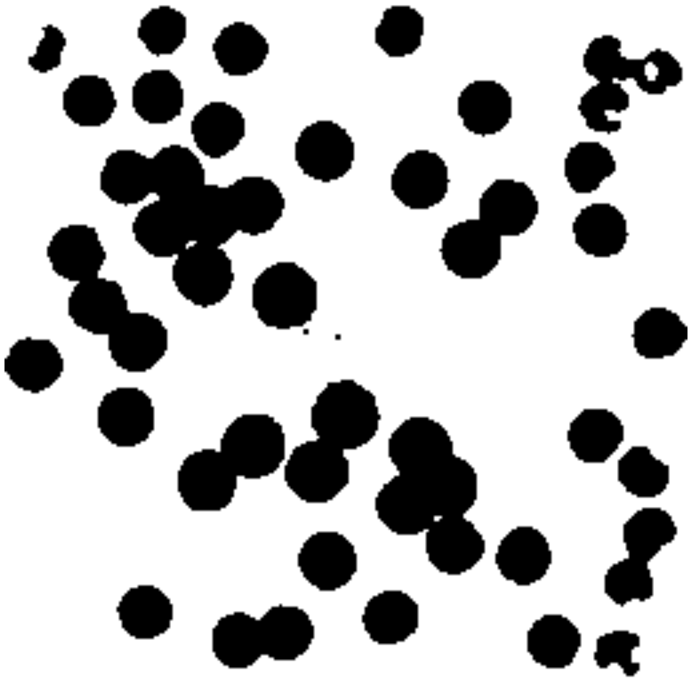


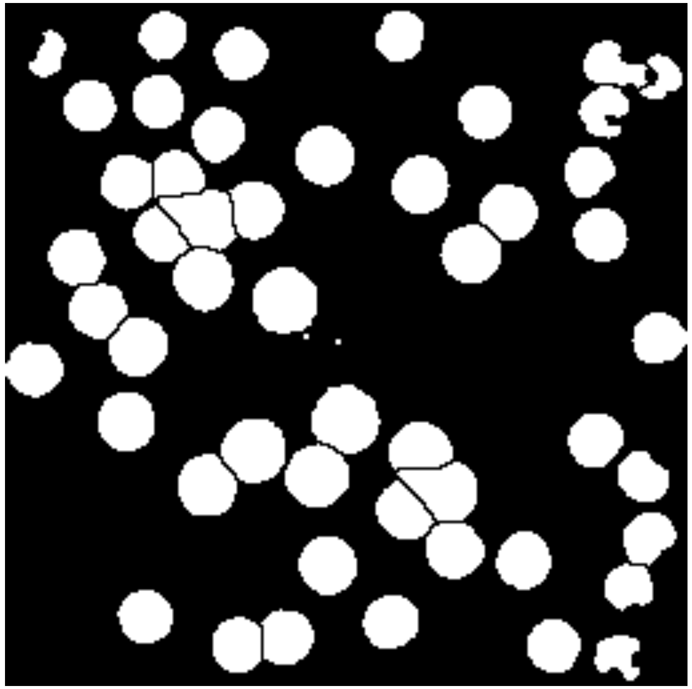
Algorithm : flooding simulation



https://imagej.net/Classic_Watershed

2 - Watershed





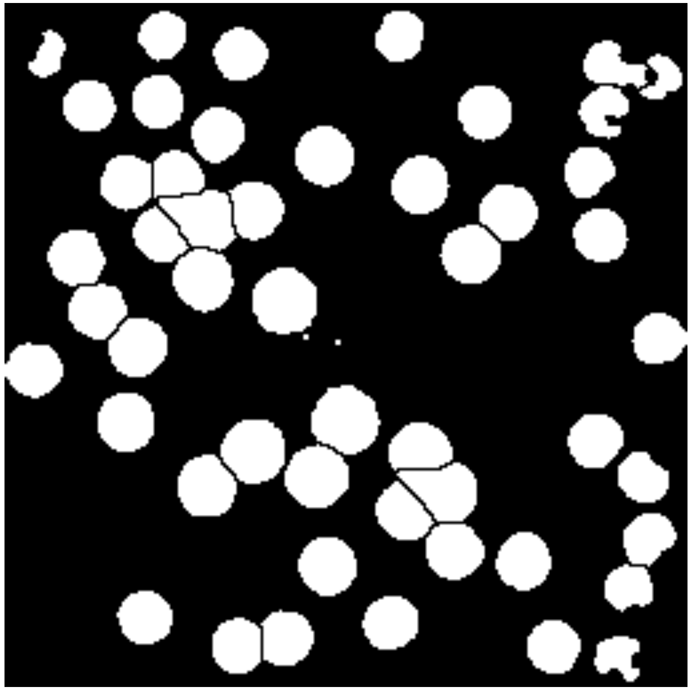
3 – Particle Analyzes

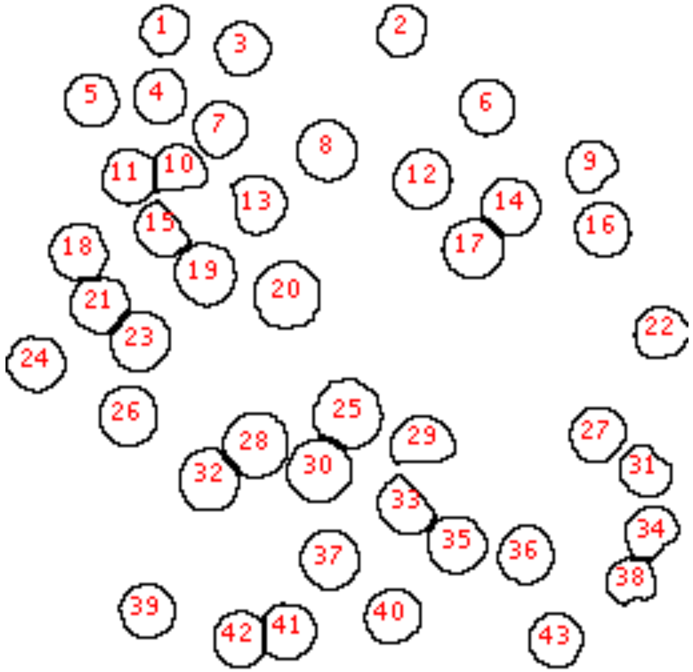
Size bounding: $S_{\min} \leq S(P) \leq S_{\max}$

Circularity bounding: $C_{\min} \leq C(P) \leq C_{\max}, C(P) = \frac{S(P)}{2\pi E(P)}$

$S(P)$: Number of pixels in particle P

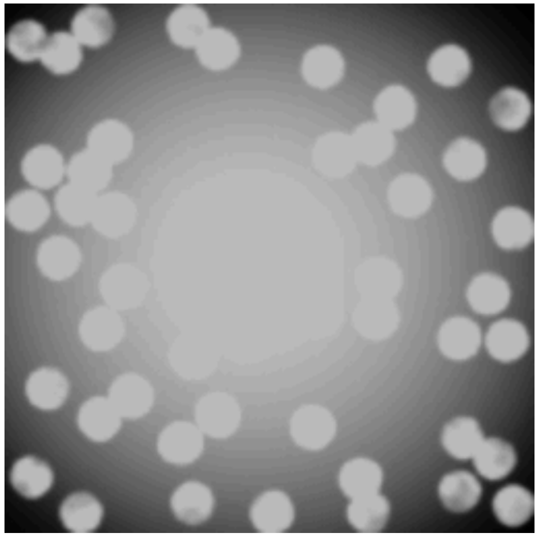
$E(P)$: Number of pixels in edge of particle P

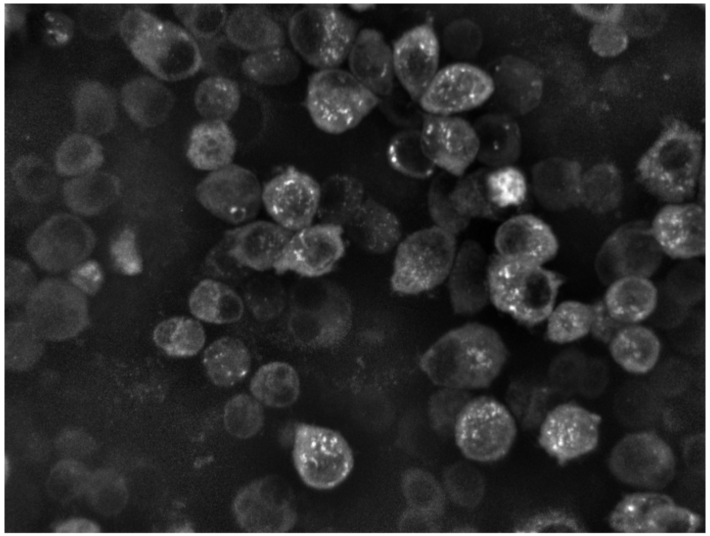




The challenges

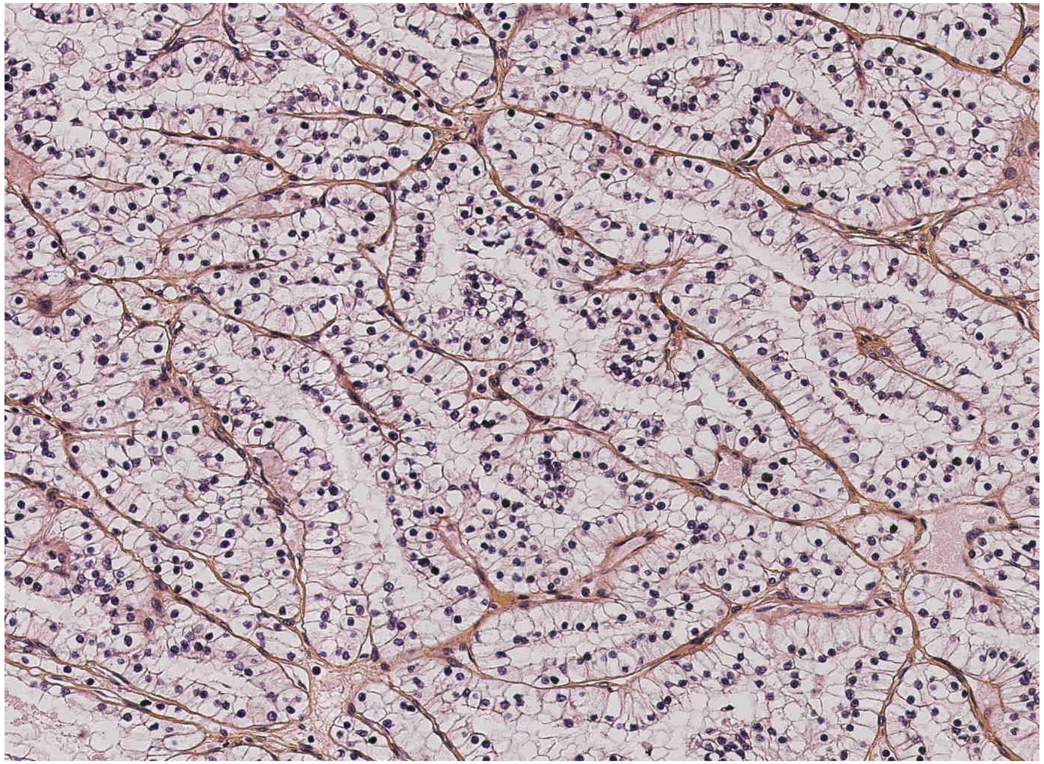
- Issue 1: How to address the intensity heterogeneity that prevents from considering a global threshold on the intensity in order to separate to objects from background ?

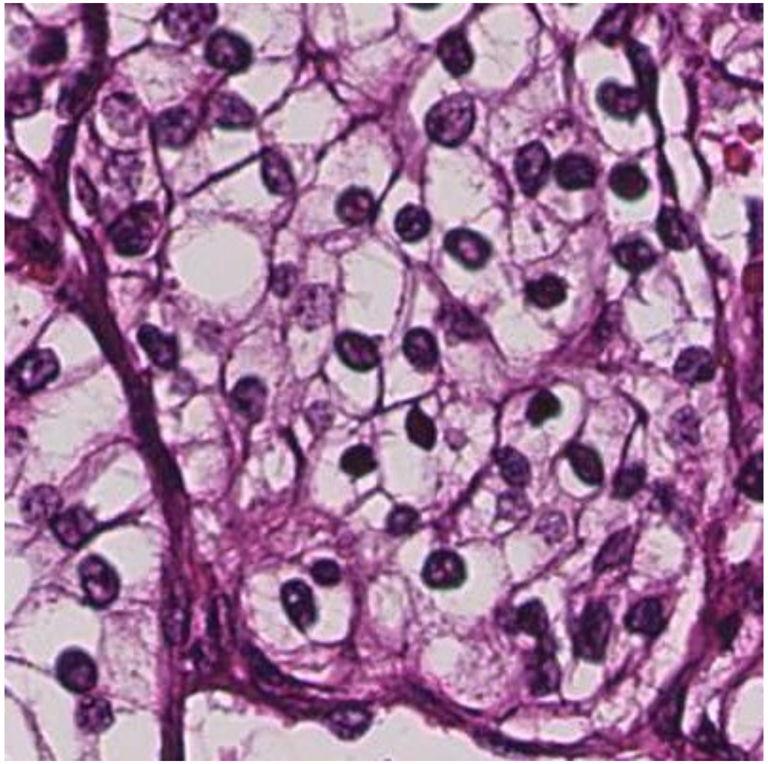




The challenges

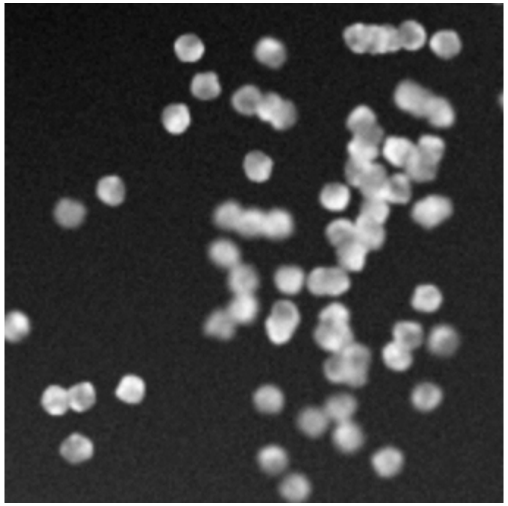
- Issue 2: How to deal with nuisance objects that do not belong to the targeted class of objects but cannot be considered as background neither ?

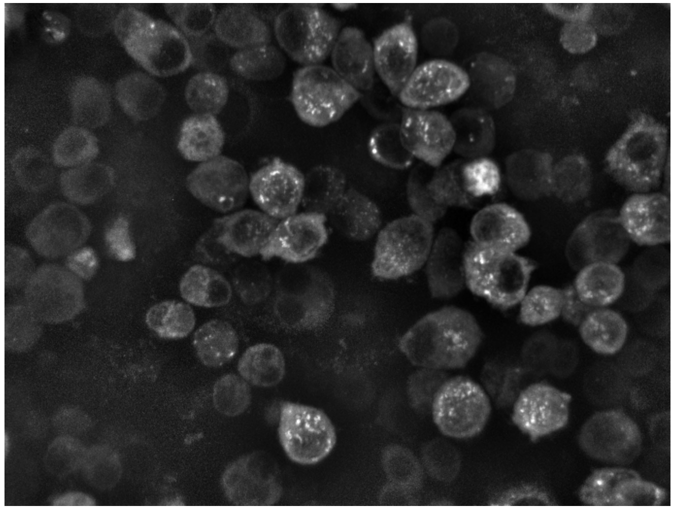




The challenges

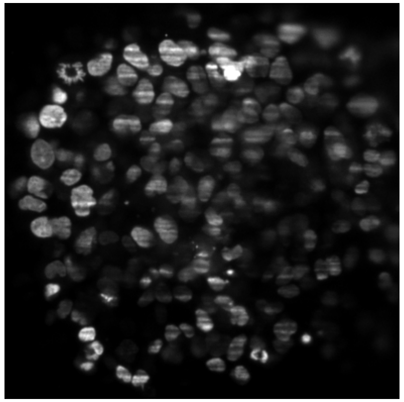
- Issue 3: How to deal with a high density of objects that generates clusters of possibly overlapping objects ?

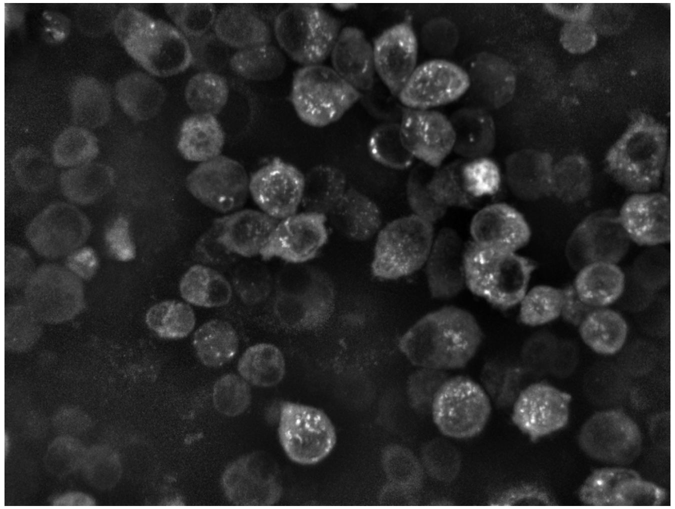




The challenges

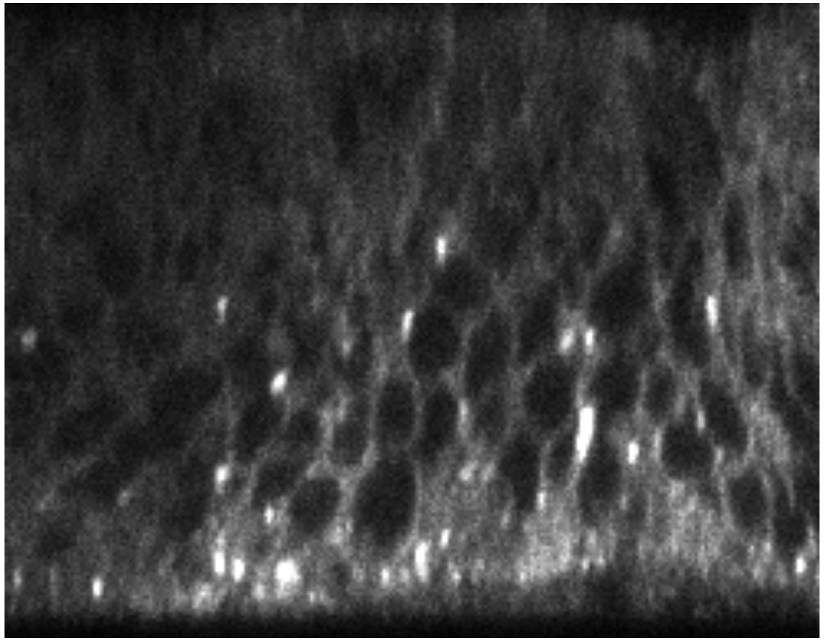
- Issue 4: How to handle the shape variability between objects ?

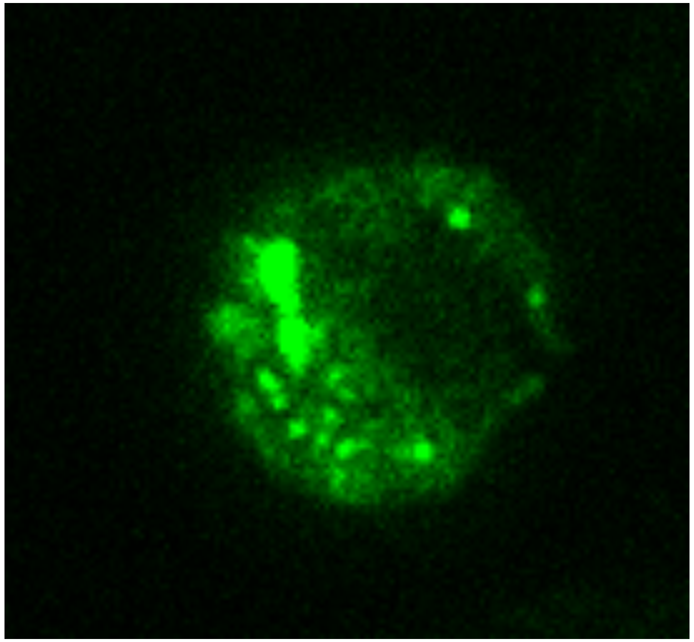




The challenges

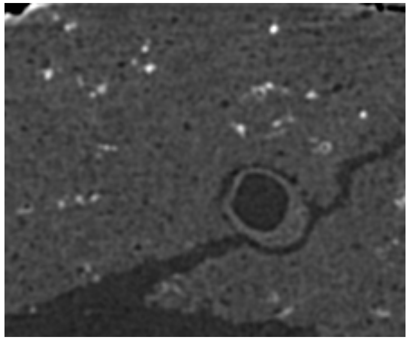
- Issue 5: How to detect objects that consist of a few pixels ?

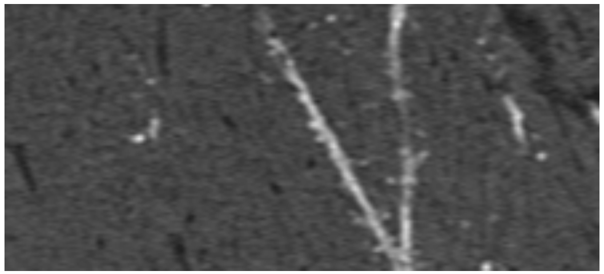


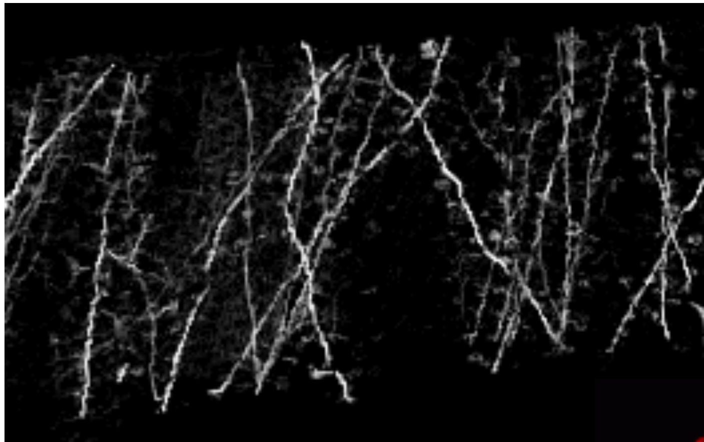


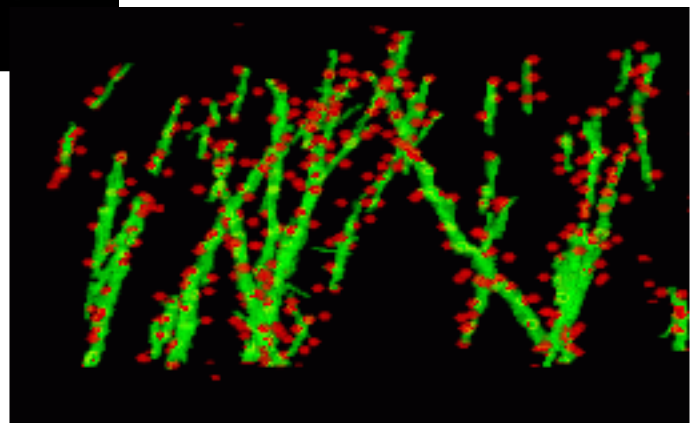
The challenges

- Issue 6: How to deal with 3D datasets ?









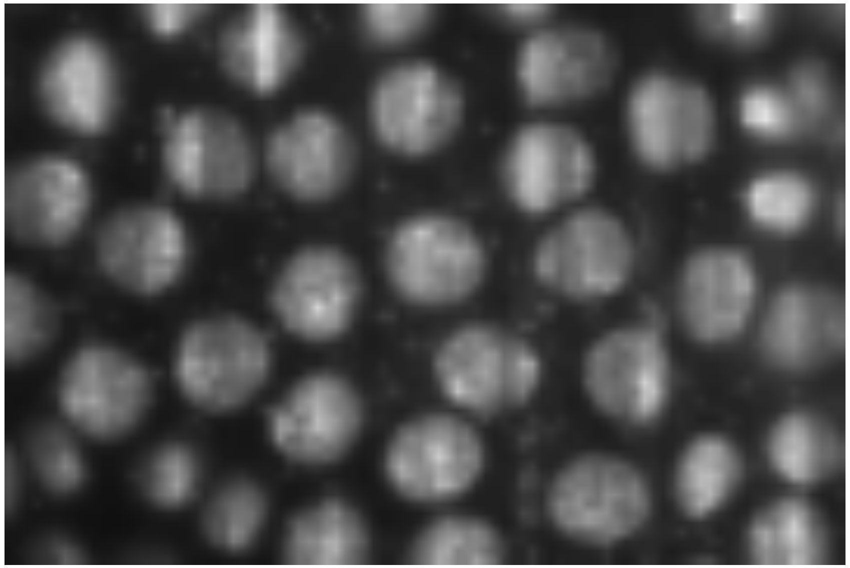
Main steps

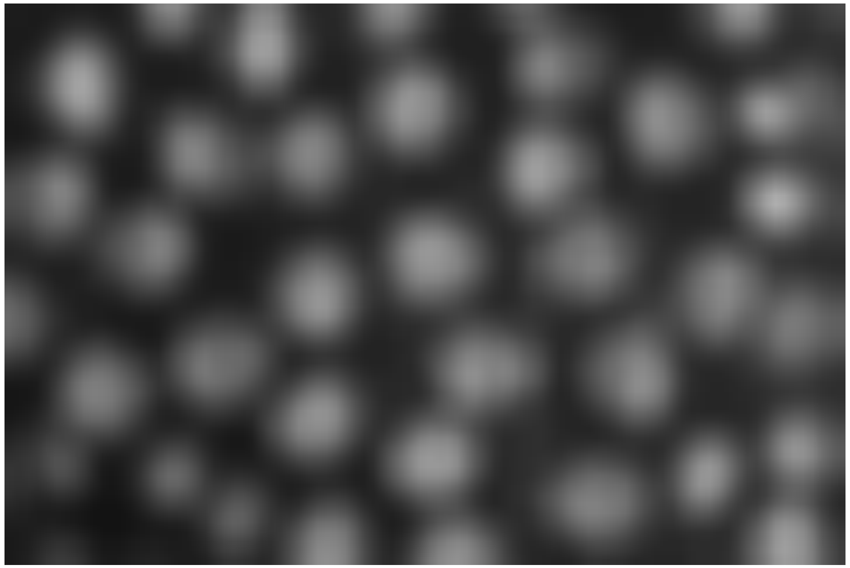
- Improve image quality :
  - Denoising : Gaussian filter, Image restoration (MRF, Variational approaches,…)
  - Spatial normalization
  - Objects enhancement : Edge enhancement, Top Hat
- Detect object location :
  - Threshold + Local maxima, template matching
- Reconstruct object shape :
  - Watershed, Active contour
- Post-processing :
  - Cleaning (opening, closing), Shape parameters
- All in One : Marked Point Processes

Denoising

- Gaussian Filter : $O = G * I$

$$G\left(x, y\right) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp - \left[\frac{x^2 + y^2}{2\sigma^2}\right]$$



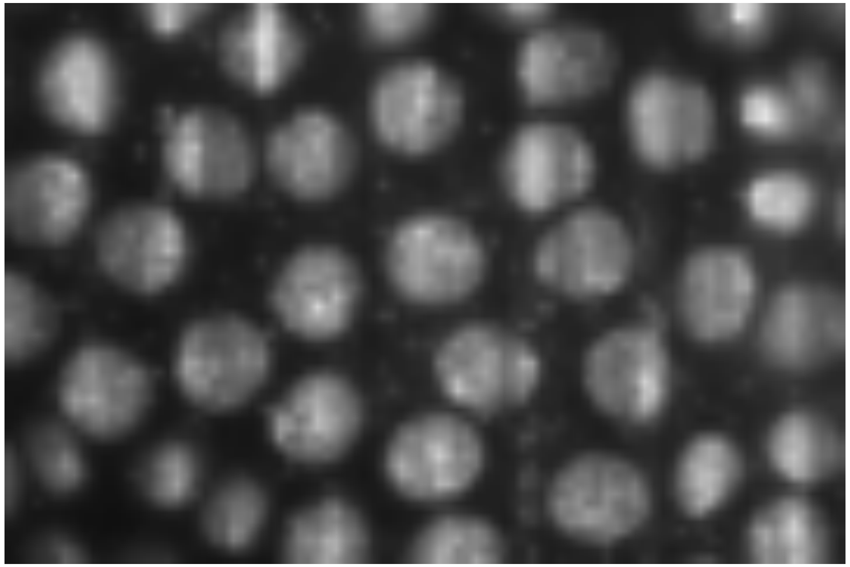


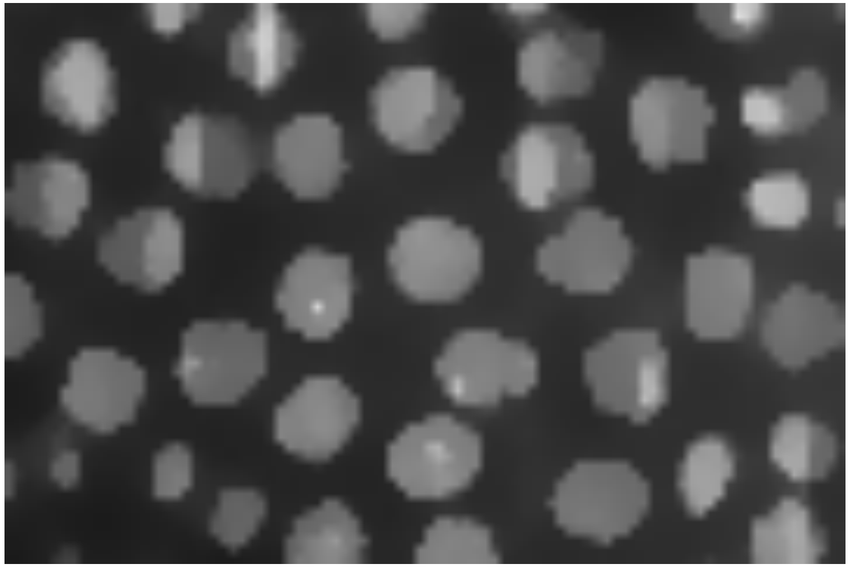
-> Remove noise but blur objects

Denoising

- Restoration : $\operatorname{argmin}\left(||O - I||_{L^n} + \Phi(O)\right)$

Example: $U = \sum_{s} \frac{(o_s - i_s)^2}{2\sigma^2} - \beta \sum_{s \sim s'} \frac{1}{1 + \frac{(o_s - o_{s'})^2}{\delta^2}}$





-> Higher algorithmic complexity, embed prior information on the solution (cf Bayesian approach).

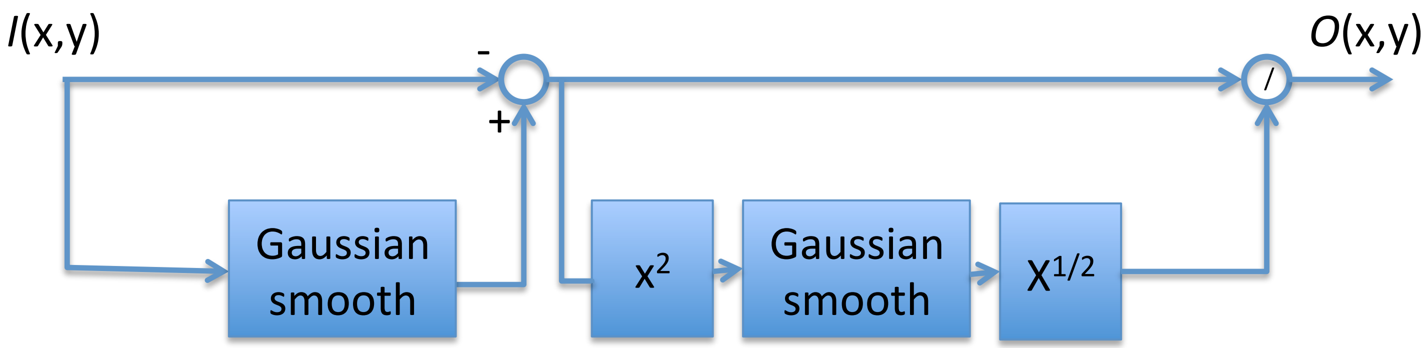
Spatial normalisation

- Goal : impose locally the same mean and variance

$$O(x,y) = \frac{I(x,y) - m_I(x,y)}{\sigma_I(x,y)}$$

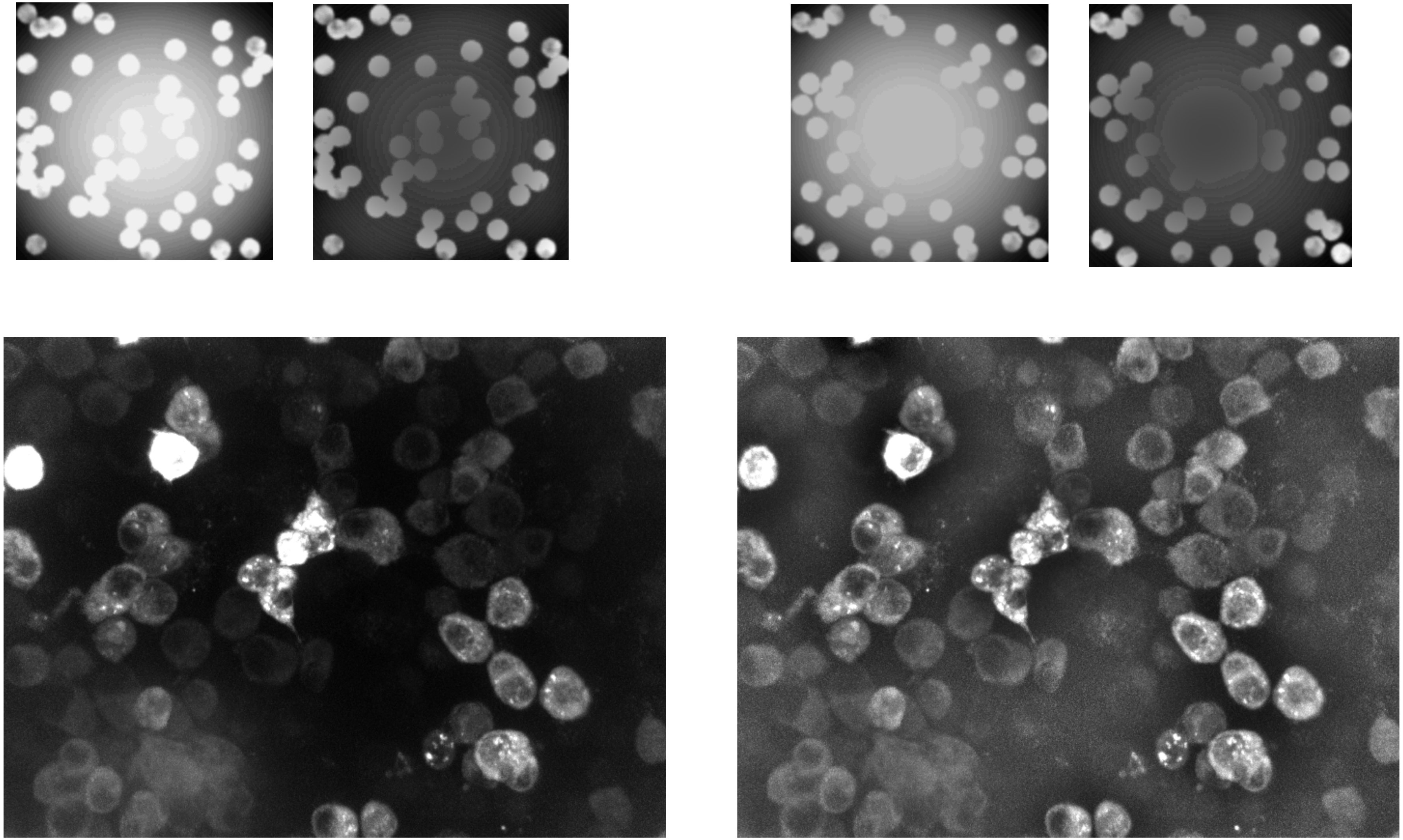
$$m_I(x,y) \ : \ \text{estimation of local mean}$$

$$\sigma_I(x,y) \ : \ \text{estimation of local standard deviation}$$



http://bigwww.epfl.ch/sage/soft/localnormalization/

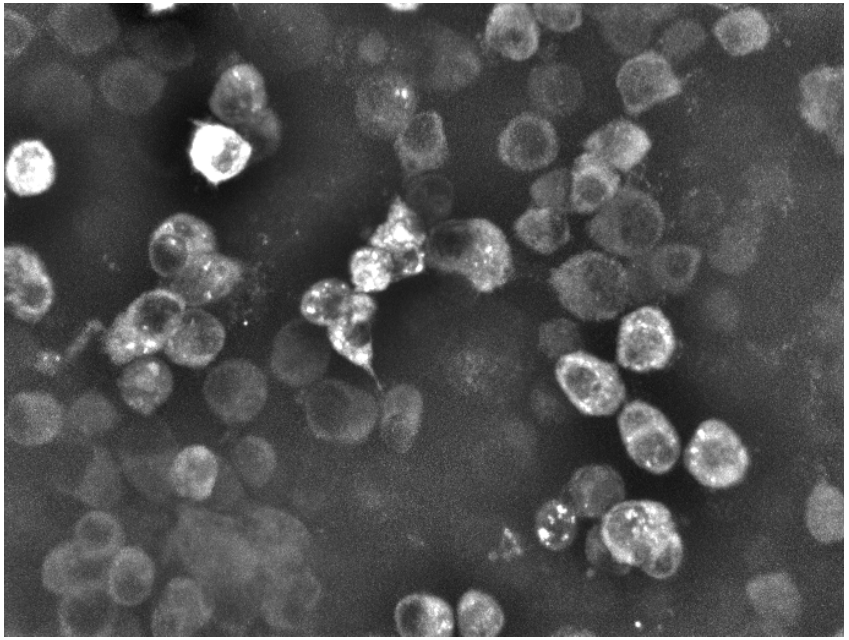
Spatial normalisation

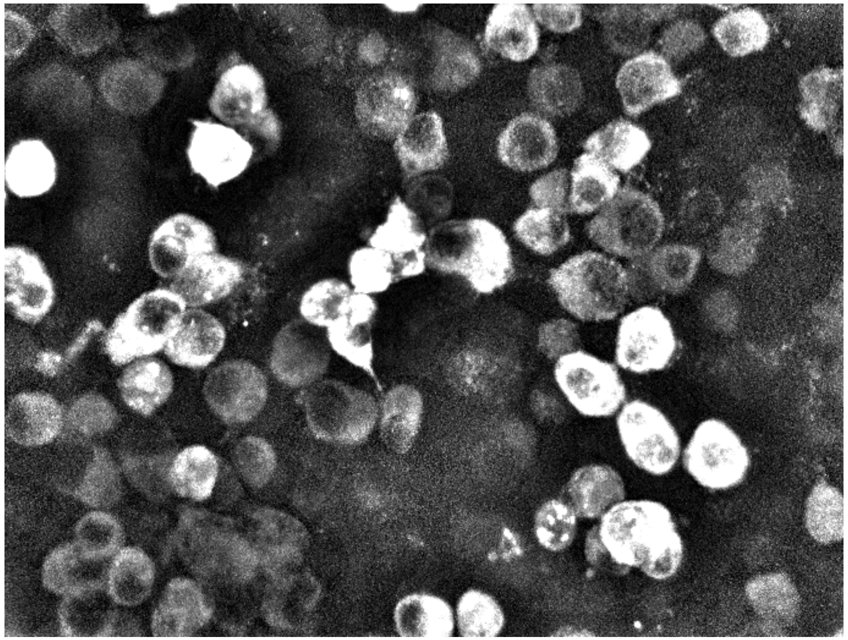


Top Hat

$$O = I - E(I, B)$$

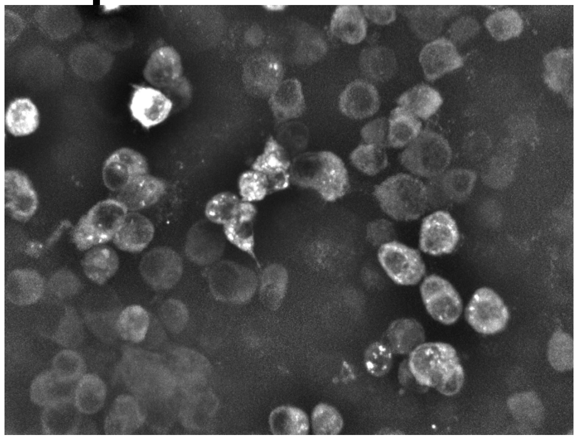
B : Object silhouette



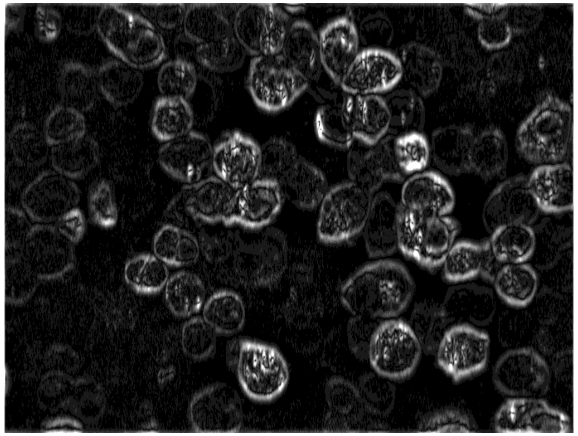


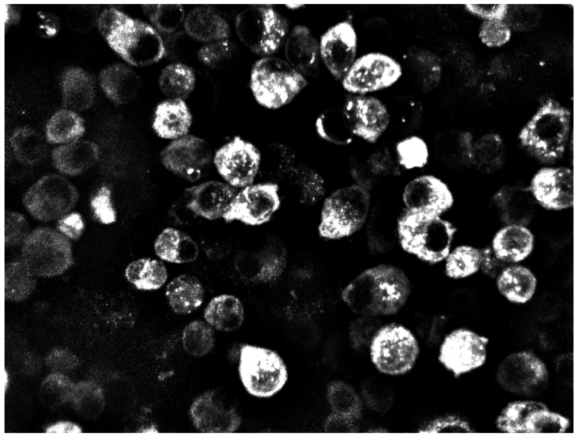
Edge enhancement

- Edge detection followed by image addition or multiplication

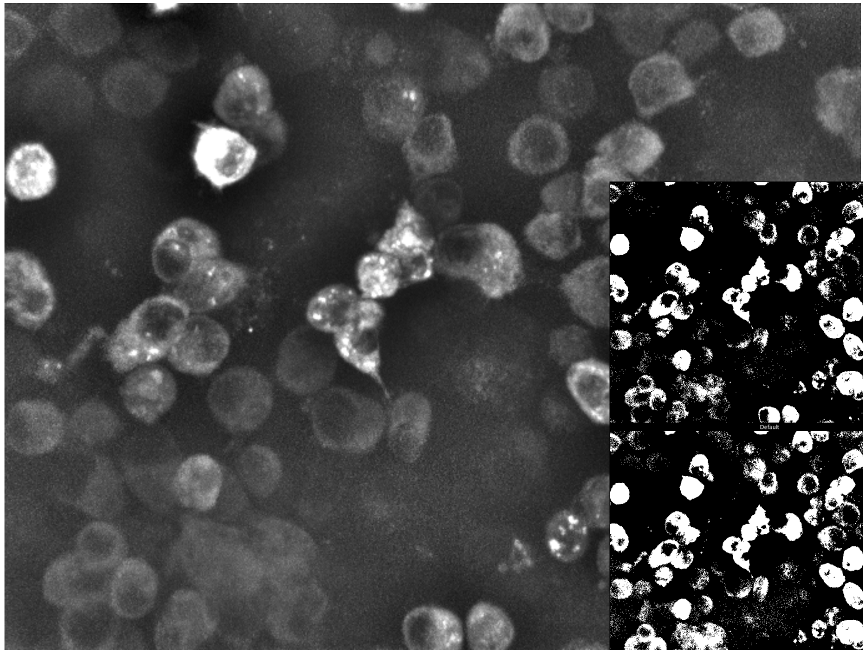


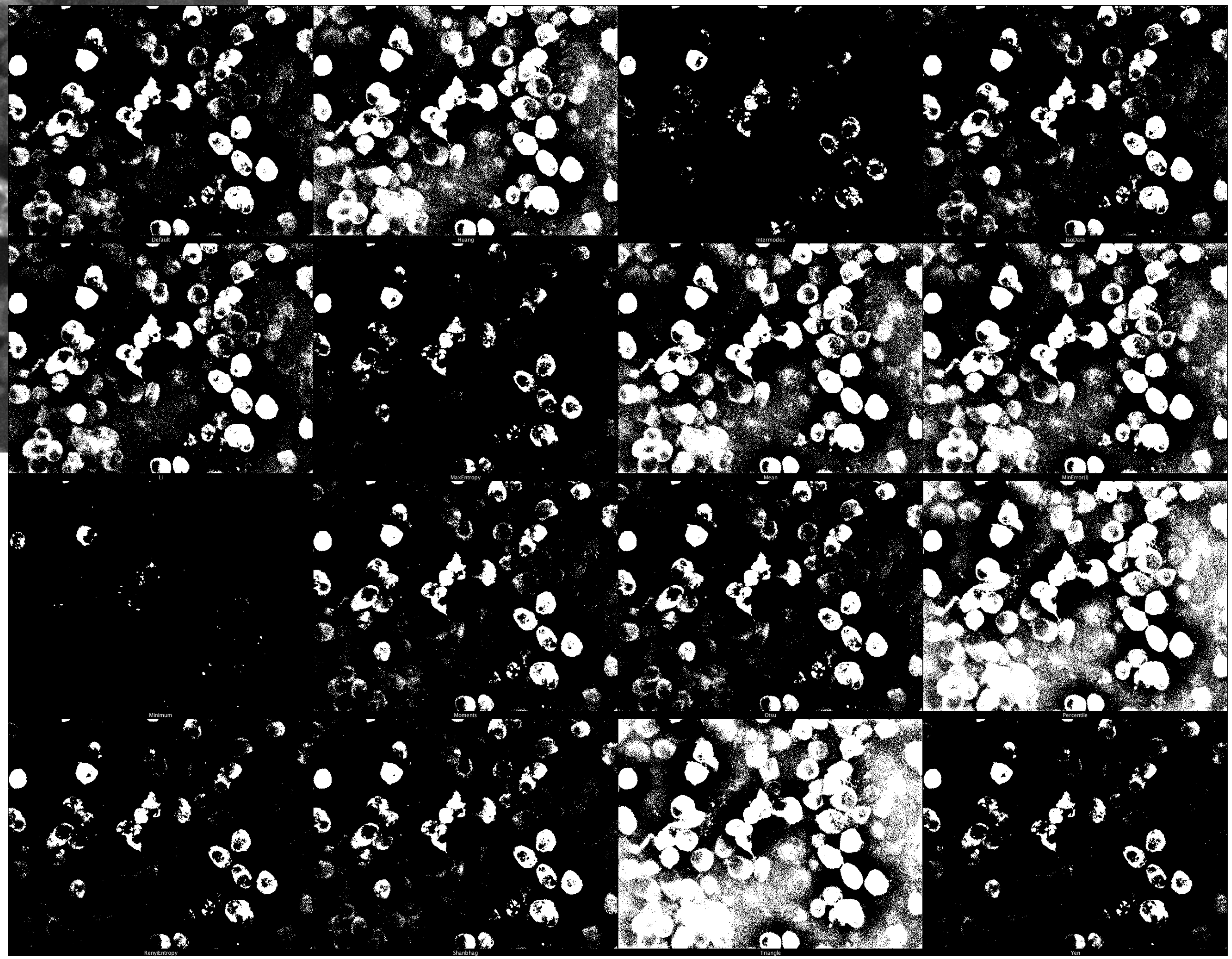
x



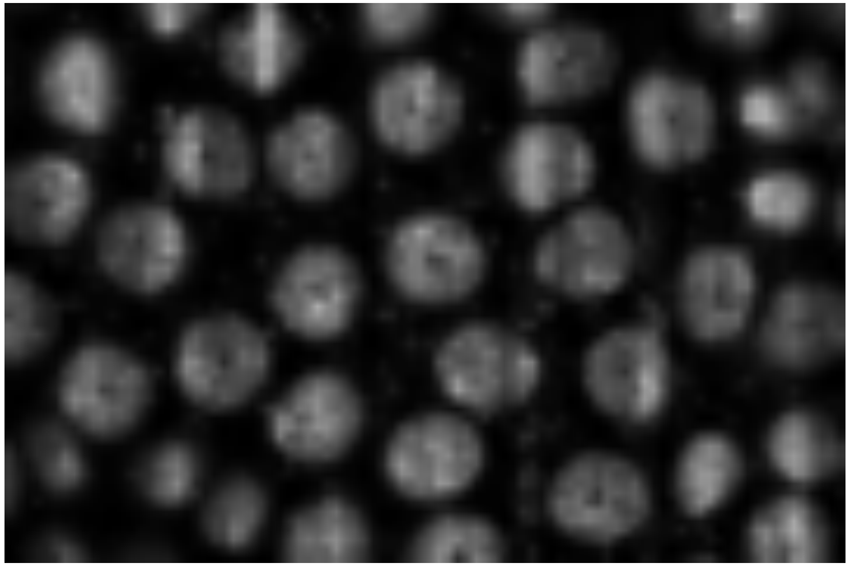


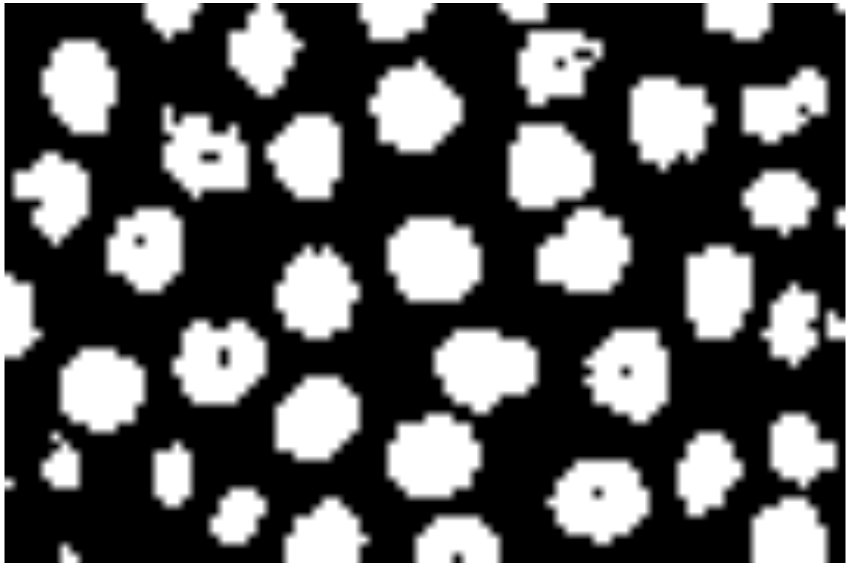
Binarization : threshold





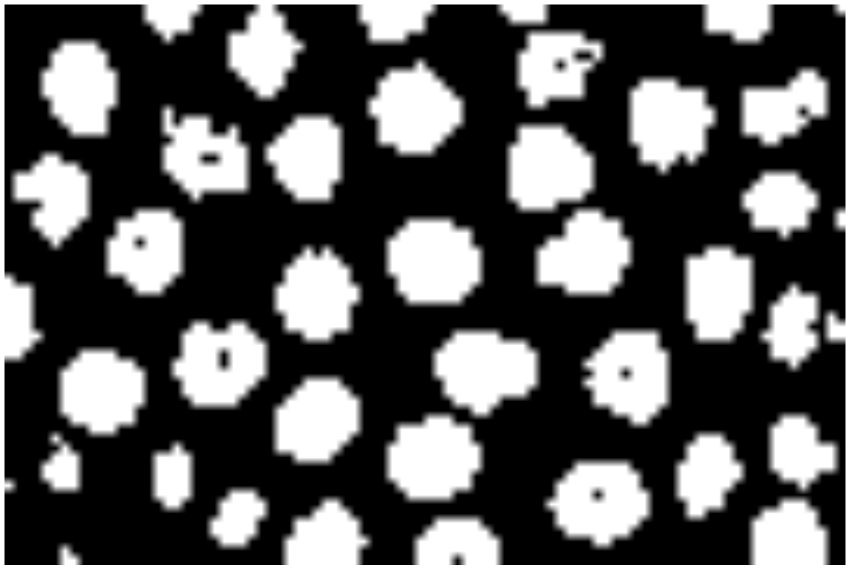
Binarization : threshold

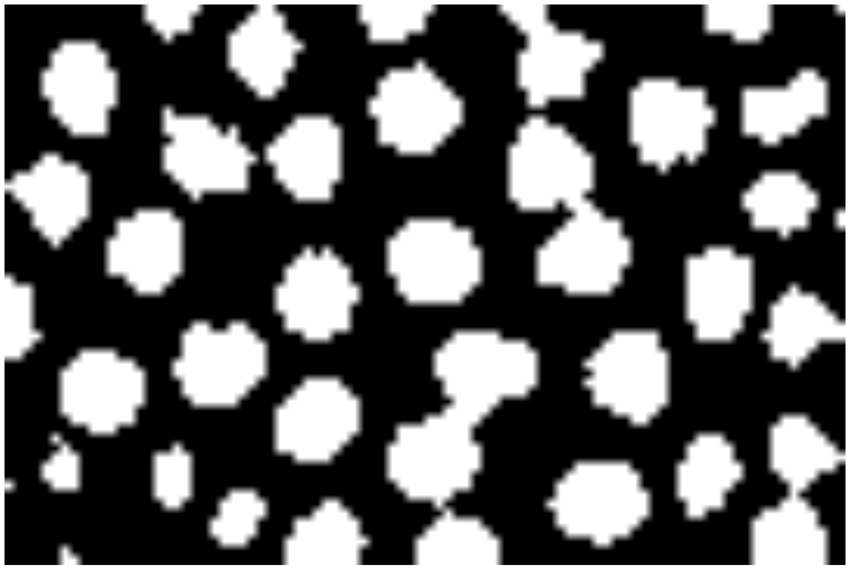




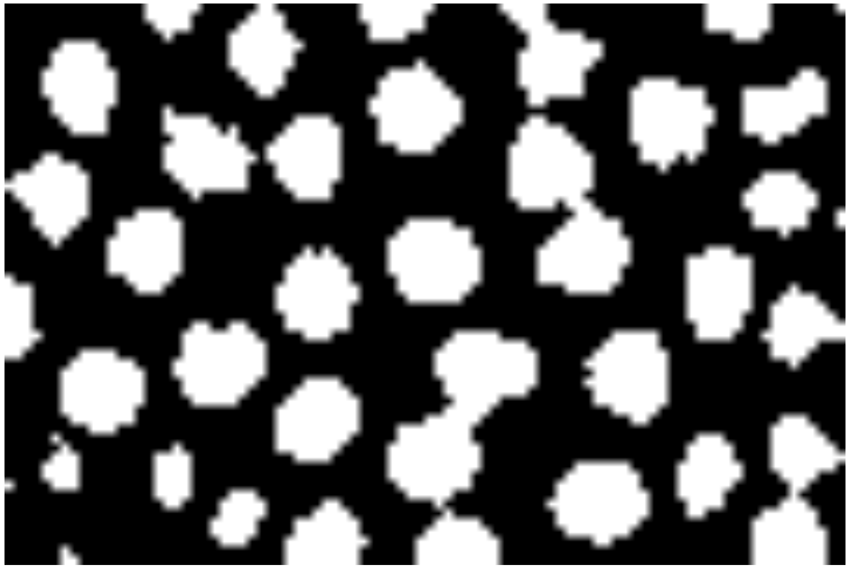
Closing

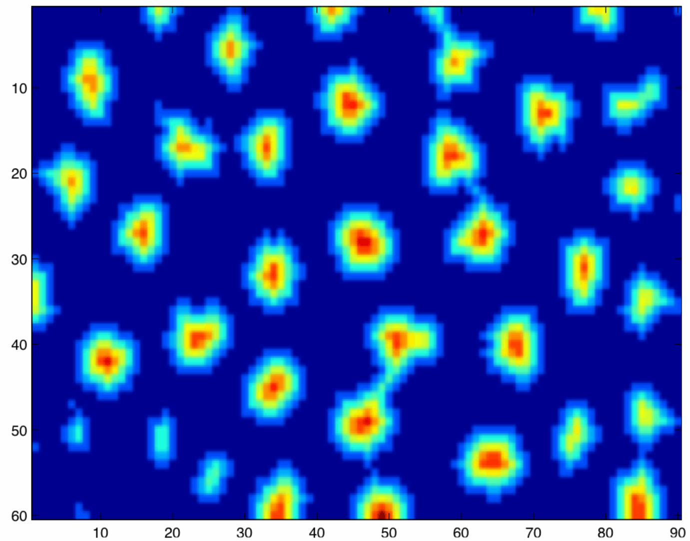
Small structuring element



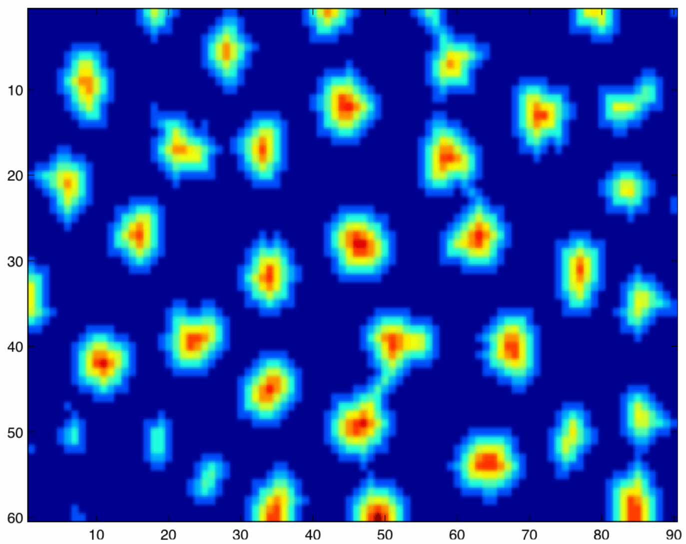


Distance map





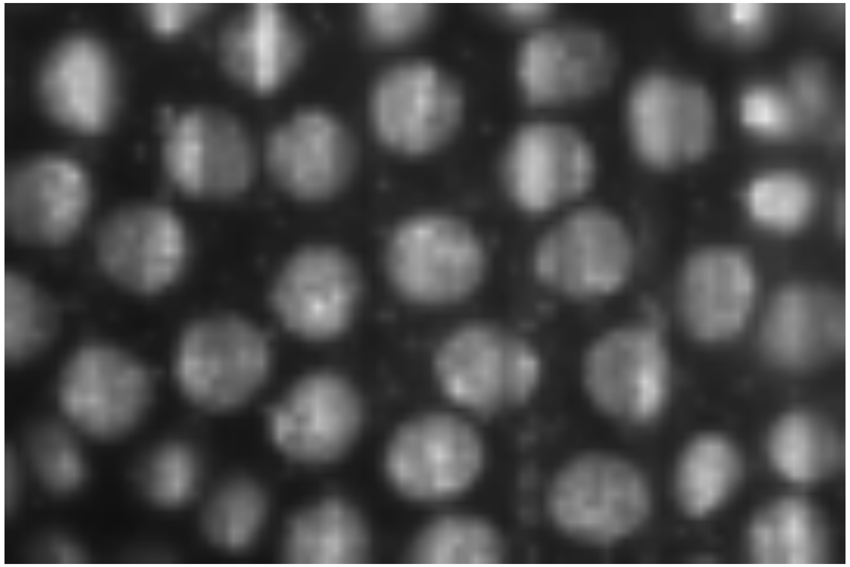
Local maxima

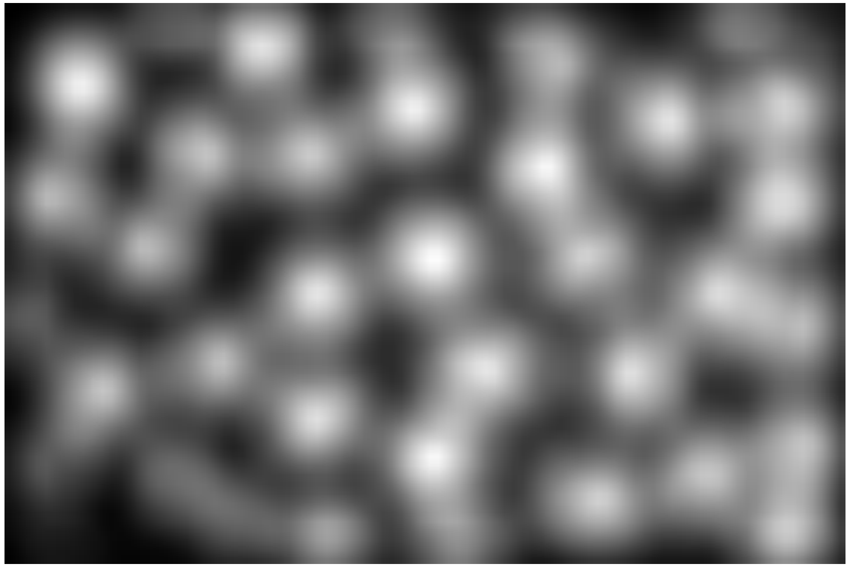


Template matching

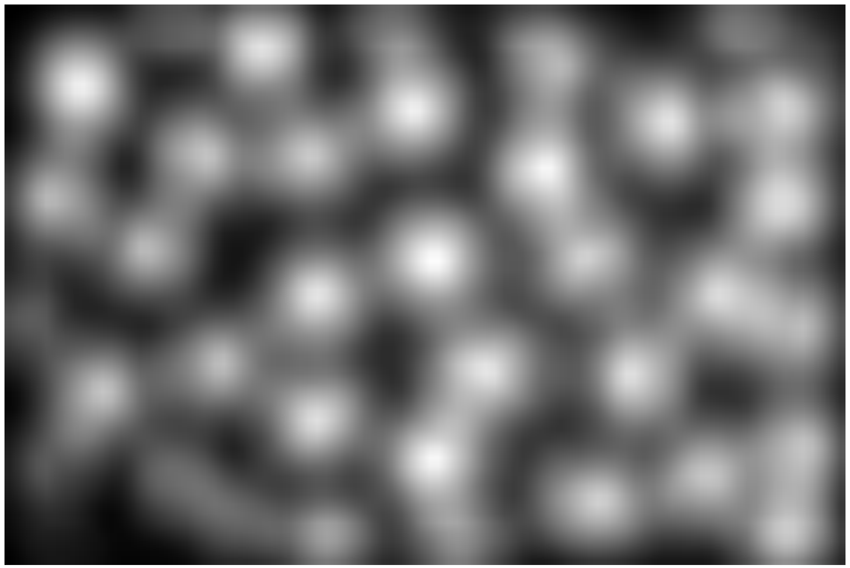
$$O = I * T$$

T : Template





Local maxima



All in One: Marked point processes

For more complex case :

- High level of noise
- Objects overlap

Idea : fit a set of objects on the data

Pros :

- Embed constraint on shapes
- Embed strutural constraint on the configuration

Cons :

- Low dimensionnal parametric shapes
- Complex algorithms

Marked point processes : construction

1) Define a « shape » space : set of disks, ellipses,…

2) Consider the set of object configurations :

3) Define an energy function on the configuration set :

4) Minimize the energy function

Marked point processes : construction

1) Define a « shape » space : set of disks, ellipses,…

M : Space of marks

Example : Disks $M = \{r, r \in [r_{\mathrm{min}}, r_{\mathrm{max}}]\}$

2) Consider the set of object configurations :

$$\Omega_0 = \emptyset \ , \ \ \Omega_n = \{\{(x_1, m_1), \ldots, (x_n, m_n)\}\, , x_i \in X, m_i \in M\}$$

$$\Omega = \cup_n \Omega_n$$

Marked point processes : construction

3) Define an energy function on the configuration set :

$$h(O) = \frac{1}{Z} \exp\left[-U(O)\right] d\pi(O)$$

π : measure of the Poisson process

$$U(O) = U_p(O) + U_d(O|I)$$

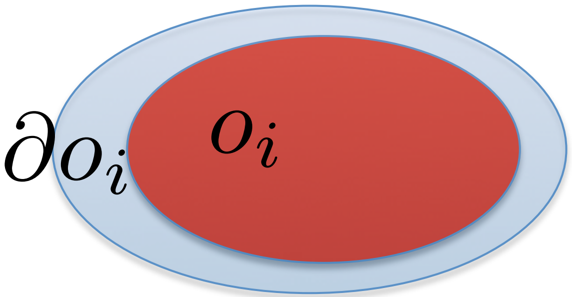
U_p : prior $\qquad$ U_d : data term

4) Minimize the energy function

- Birth and death
- RJMCMC
- Multiple births and Deaths
- Multiple births and cut

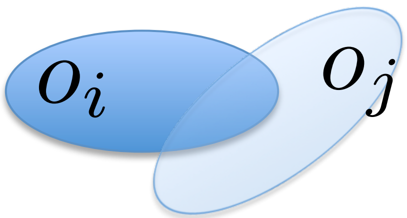
$$\hat{O} = \arg\min U(O)$$

Marked point processes : example



$$U_d(O|I) = \sum_i u_d(o_i)$$

$$u_d(o_i) = T - \frac{\mu(o_i) - \mu(\partial o_i)}{\sqrt{\sigma^2(o_i) + \sigma^2(\partial o_i)}}$$

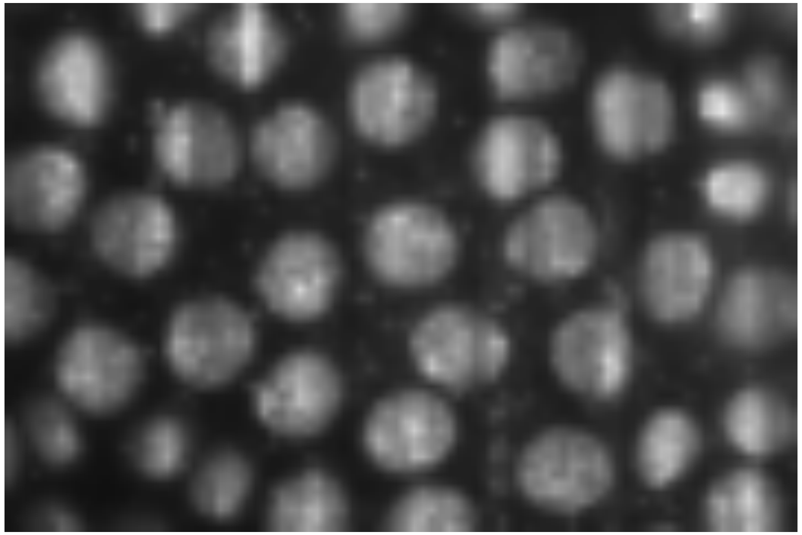


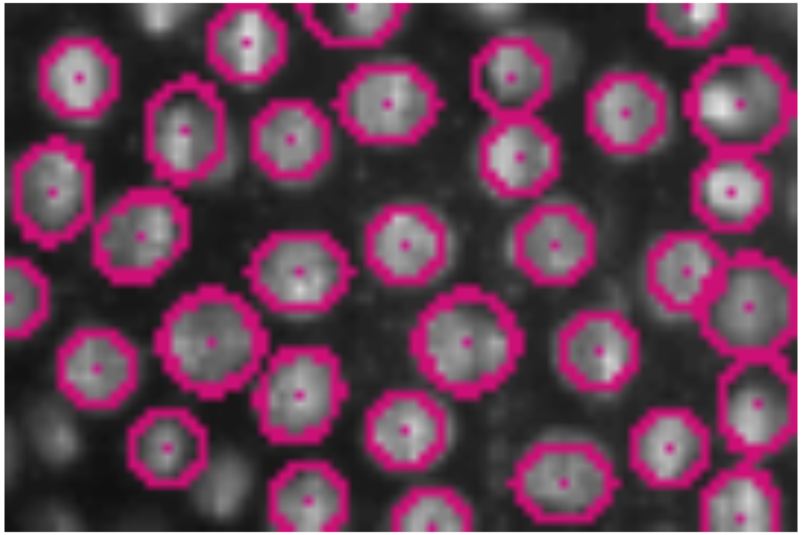
$$U_p(O) = \sum_{i \sim j} u_p(o_i, o_j)$$

$$u_p(o_i, o_j) = \begin{cases} 0 \text{ if } \frac{|o_i \cap o_j|}{\min(|o_i|,|o_j|)} < p \\ P \text{ otherwise} \end{cases}$$

Marked point processes

Data term : Battacharrya distance
Priori : non overlap
Optimization : Mutiple Births and Deaths





Flamingos detection