Morphological Methods for Multi-focus Image Fusion

(Dedicated to Prof. J. Serra)

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Outline

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  - Generic Framework of Fusion Schemes
- Fusion by Computational methods
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    - ✓ Region-based method
- Performance comparison
- Conclusion

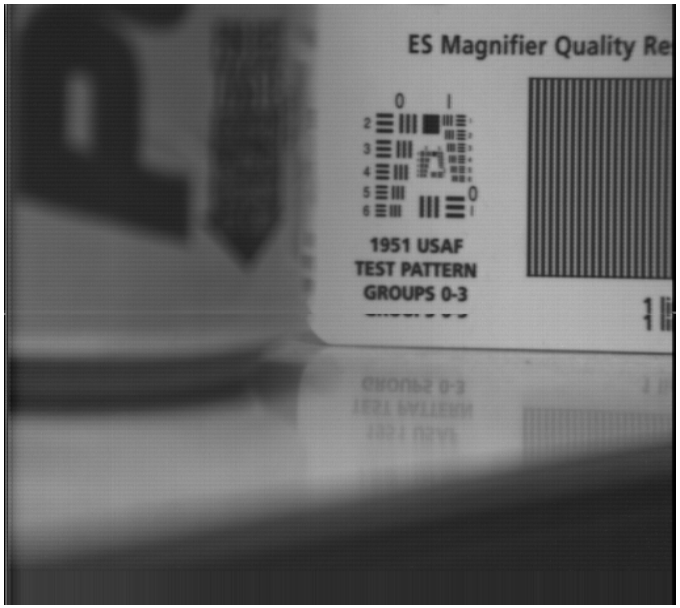
Problem and Motivation

- A scene to be photographed by a camera includes objects at varying distances from the camera.
- Suppose an object focused by the camera is at a distance f from the camera
- This object appears to be the sharpest in the image.

Problem and Motivation

- Other objects at distance f from the camera also appear sharp in the image.
- But this sharpness reduces gradually as the object-distance d differ much from f.
- The sharpness reduction is not significant if $|f - d| < r$, the *depth-of-field (DOF)*.

Example: Multi-focus Images



Focus on background

Focus on foreground

Depth of Field

DOF depends on various factors:

- **Aperture of the camera**: DOF increases as the aperture of the camera decreases.
- **Distance of the focused object**: DOF increases as the distance f increases.

Pin-hole camera: Infinite DOF

- Aperture is reduced to a pin-hole and *DOF* becomes *infinite*.
- But the light energy incident on the image plane is reduced considerably, hence image-quality becomes poor.
- So *camera* with *significant aperture* is preferred, even if it has a finite DOF.

Finite DOF: Problem

They are unable to produce an image with uniform clarity everywhere because

- The objects whose distances are within the DOF appear sharp in the image.
- The objects which are located outside DOF appear blurry.

A computational solution

One of the ways to increase the effective DOF is *multi-focus image fusion.*

It may be done by

- Capturing several images of the scene with focus on objects at different distances.
- Combining these images to get an image in which all objects appear to be in focus.

Example: Multi-focus Image Fusion

Focus on background

Focus on foreground

Focus everywhere (fused image)

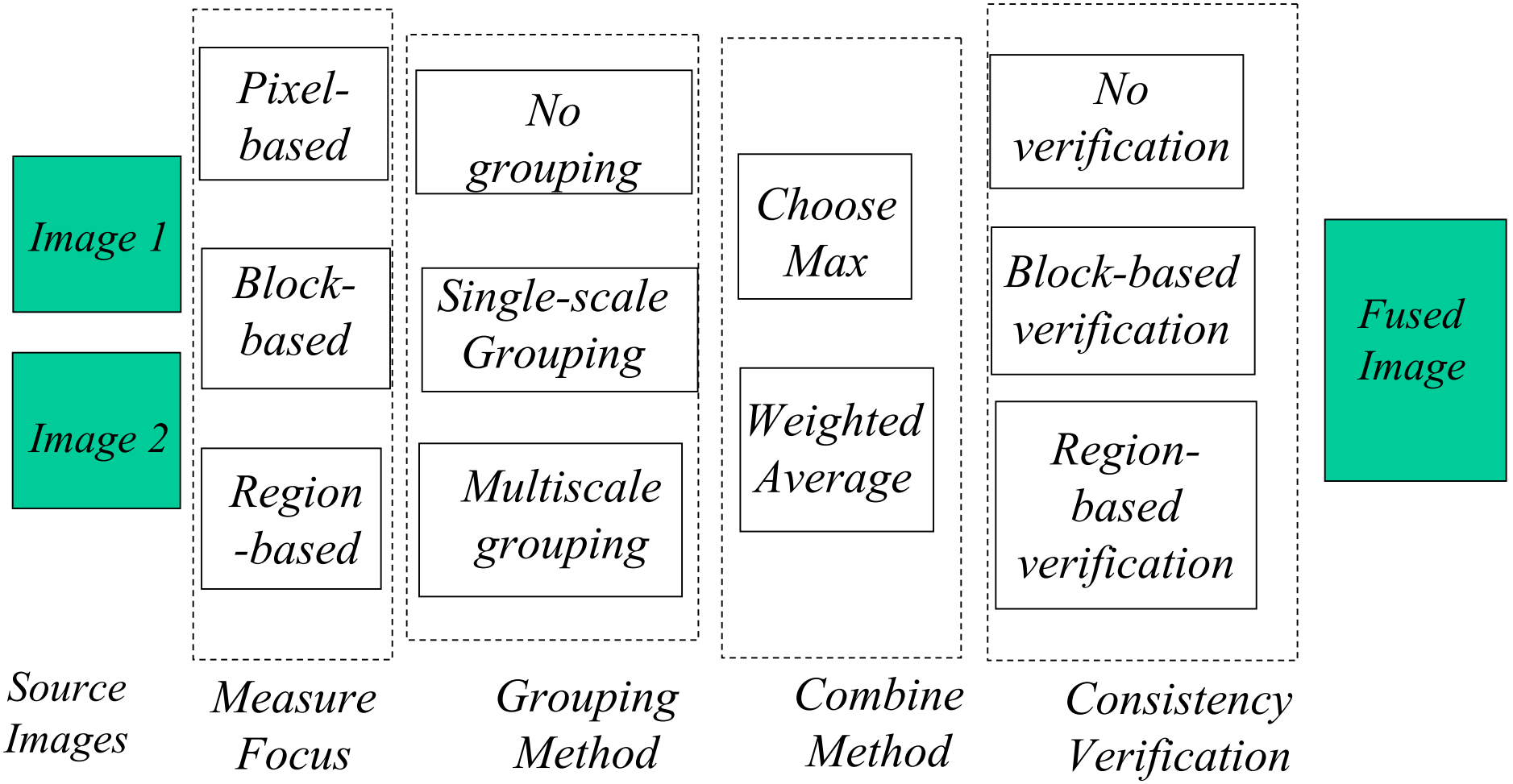
Fusion: Basic strategy

- Consider a set of multi-focus images.
- In each image find out the portions (regions to pixels) which are in better focus than corresponding portions in the other images.
- Combine these portions to get an image whose focused area is more than that of any of the source images.

Fusion: Basic strategy (contd.)

- Obs: sharp focus produces strong edges and fine details that leads to high frequency components.
- So high frequency content is more in focused portions than in corresponding defocused portions.
- Some focus measure for quantification of high frequency content is used for detecting the focused portions.

Generic Framework of Image Fusion Schemes



Block-based image fusion

- The images are divided into fixed (or variable) size blocks.
- Edge energy is considered as focus measure
  - On each block sum of square of gradient is computed and taken as edge energy.
  - The block, which has maximum edge energy, is supposed to be in focus.
- Blocks in focus are put to mosaic together.

Focus Measure: Energy of Morphologic gradient (EOMG)

- Edge strength due to morphologic gradient *G(r,c)* at point *(r,c)* is calculated as the sum of *dilation* and *erosion residue* at that point, i.e.,

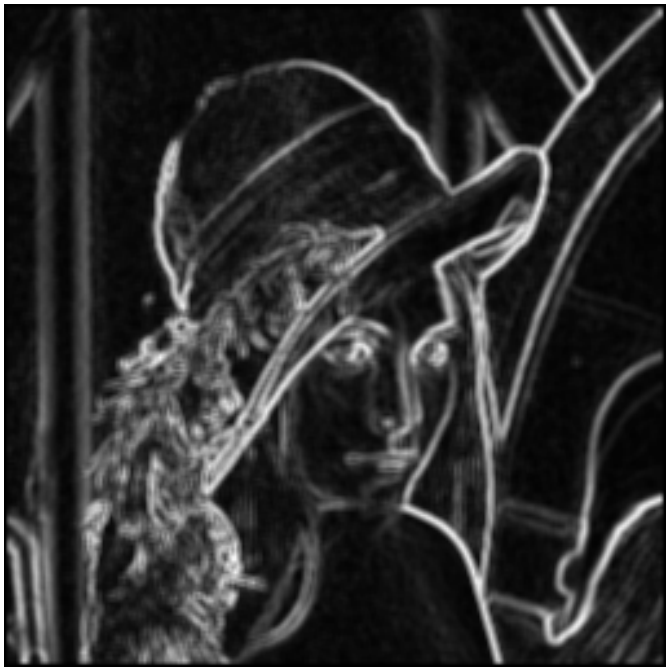
$$G(r,c) = f(r,c) \oplus h(r,c) - f(r,c) \Theta h(r,c)$$

- Energy of morphologic gradient is

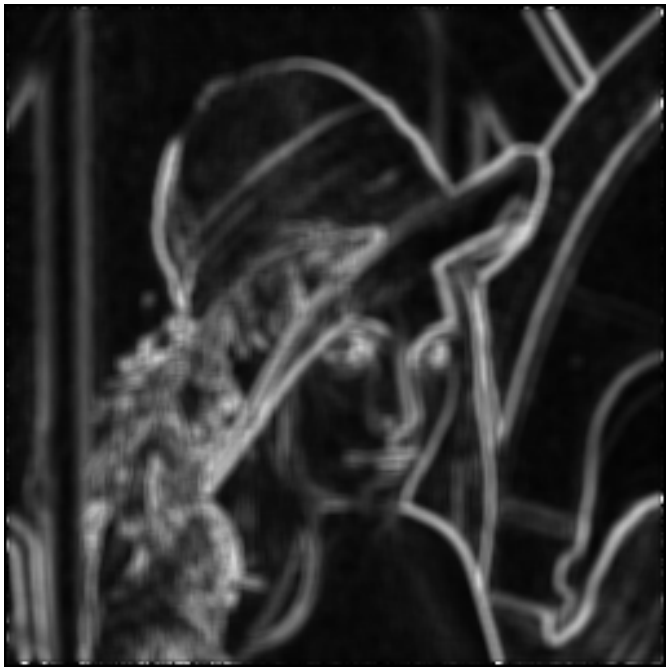
$$EOMG = \sum_r \sum_c (G(r,c))^2$$

Focus and gradient -1

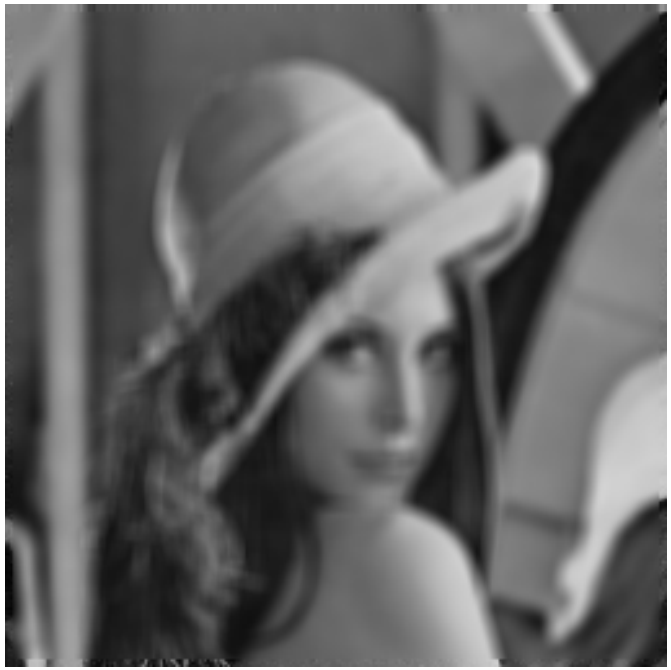
Focus and gradient -2

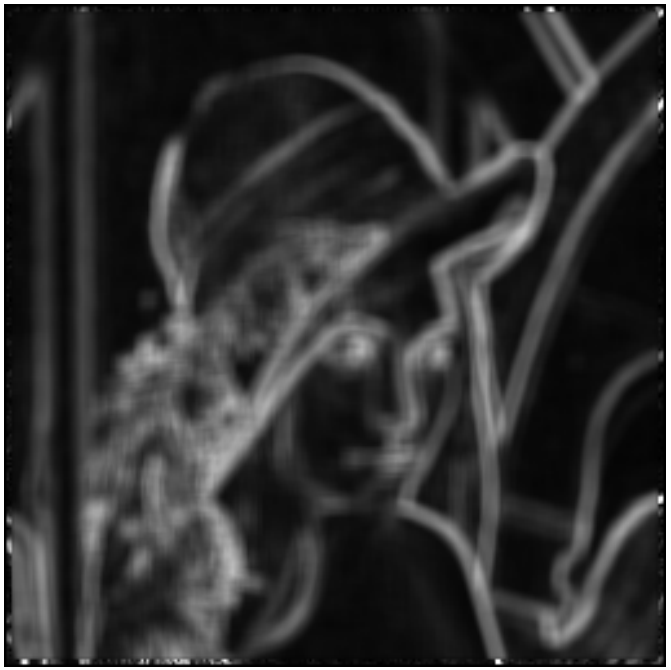


Focus and gradient -3

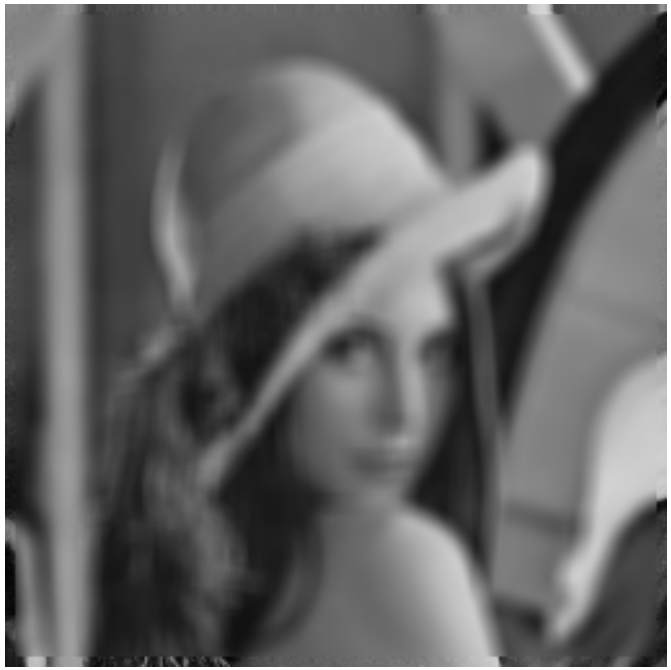


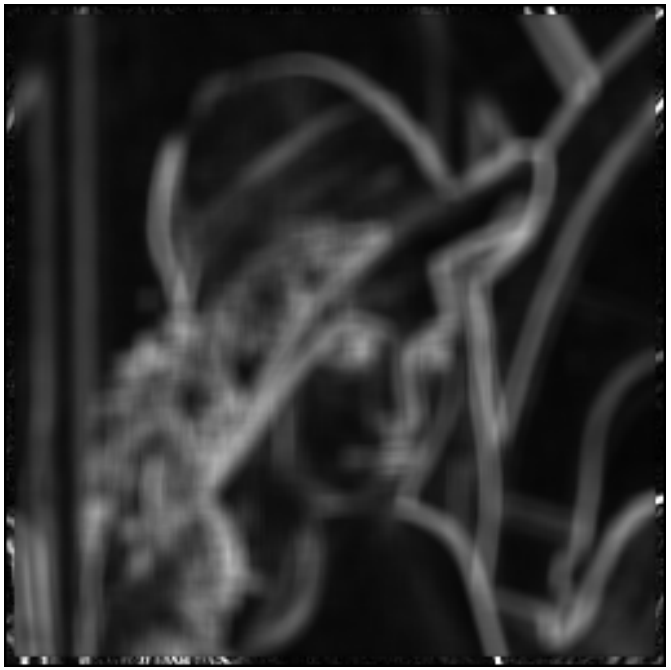
Focus and gradient -4



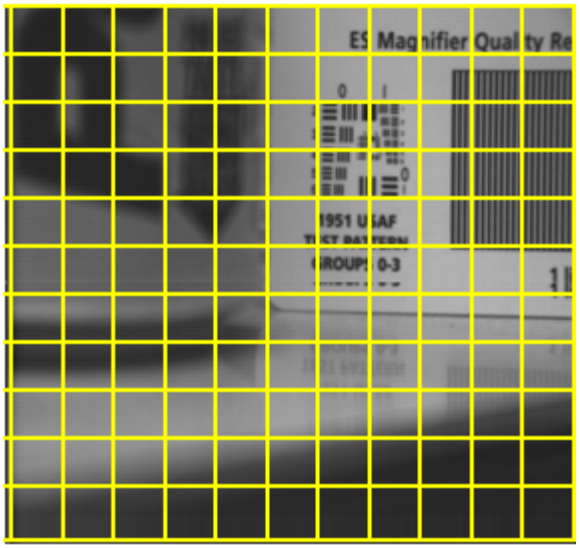


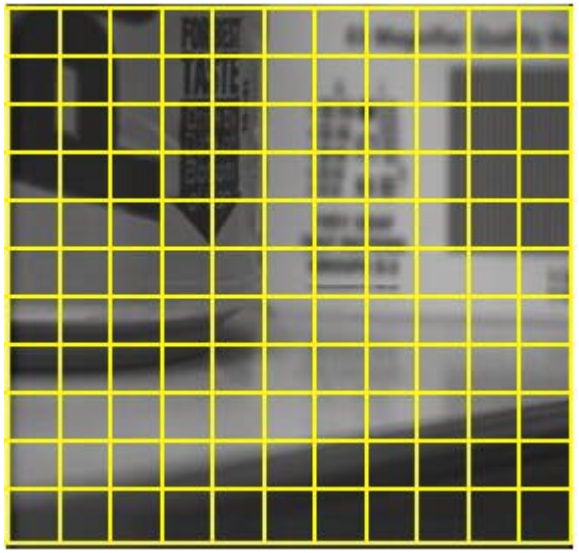
Focus and gradient -5





Block-based approach





Block-based Image Fusion

Focus on background

Focus on foreground

Focus everywhere (fused image)

Region-based Algorithm

- Uses multi-scale morphology.
- Focused regions from source images are detected by using multi-scale morphological top-hat transformation.
- Fused image is reconstructed by combining (stitching) these regions.

Why Multi-scale Morphology?

- Multi-scale morphology can detect shape information at different scale using SE of different size.
- Thus it can help detecting the sharply focused region(s) by detecting fine details.
- In other words, high population of fine details mark the sharply focused region.

Multi-scale Top-hat Transform

- It uses multi-scale opening and closing of image g by structuring element B
- $d_o^{(n)}(x,y) = (g \circ (n\text{-}1)B)(x,y) - (g \circ nB)(x,y)$
- $d_c^{(n)}(x,y) = (g \bullet nB)(x,y) - (g \bullet (n\text{-}1)B)(x,y)$
- $d_o^{(n)}(x, y)$ contains bright features of size greater than or equal to $n\text{-}1$ but less than n
- Similarly, $d_c^{(n)}(x, y)$ contains all dark features within the same range of size.

Multi-scale Top-hat Transform

- Feature (fine detail) image

$$D^{(n)}(r,c) = \max\{d_o^{(n)}(r,c), d_c^{(n)}(r,c)\}$$

- $D^{(n)}(r,c)$ contains all image features of size within the range $[n-1, n)$.
- Value of n is guided by the size of noise particles and object grain (texture).

Region-based fusion: Algorithm

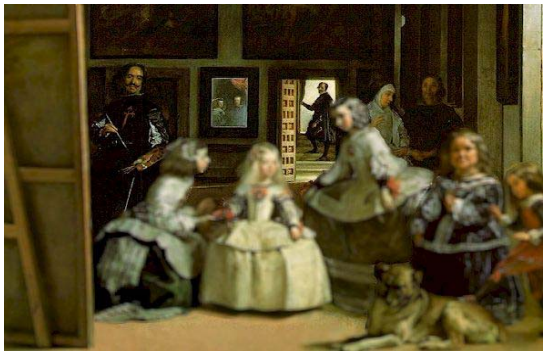
Suppose $\{g_j, j=1,2,...,k\}$ is a set of multi-focus images

- Detect focused regions using morphological top-hat transformation at scale n
- Use opening and closing to get solid blobs of focused regions
- Copy the corresponding regions from the multi-focus images to form the fused image.

Example of multiscale algorithm

a

b



c

d

e

f

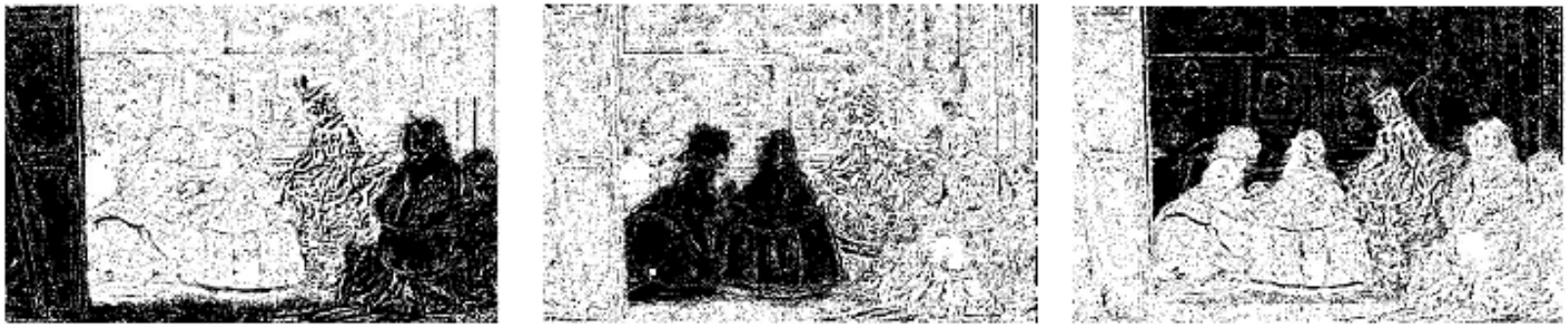
A set of multi-focus color images and their registered gray-level version

Binary images corresponding to focused regions detected at various scales



For near-focused image using (a) 2x2 SE (b) 4x4 SE, (c) 8x8 SE

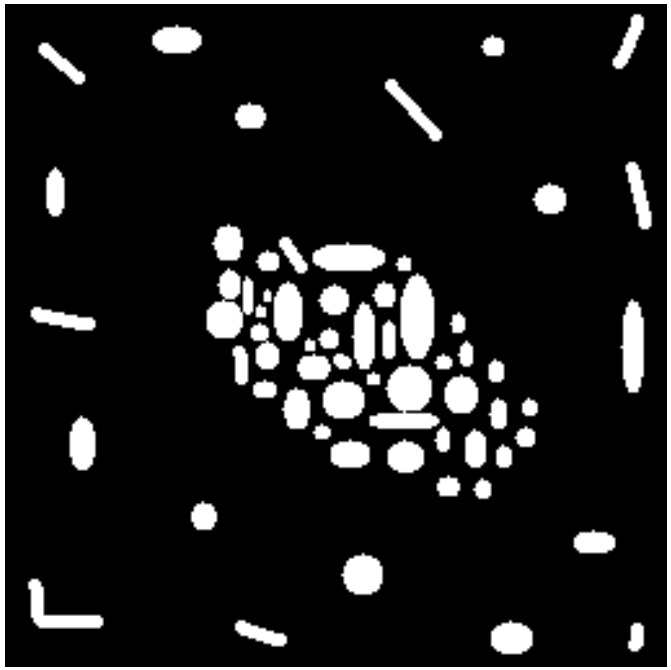
Binary images depicting focused regions



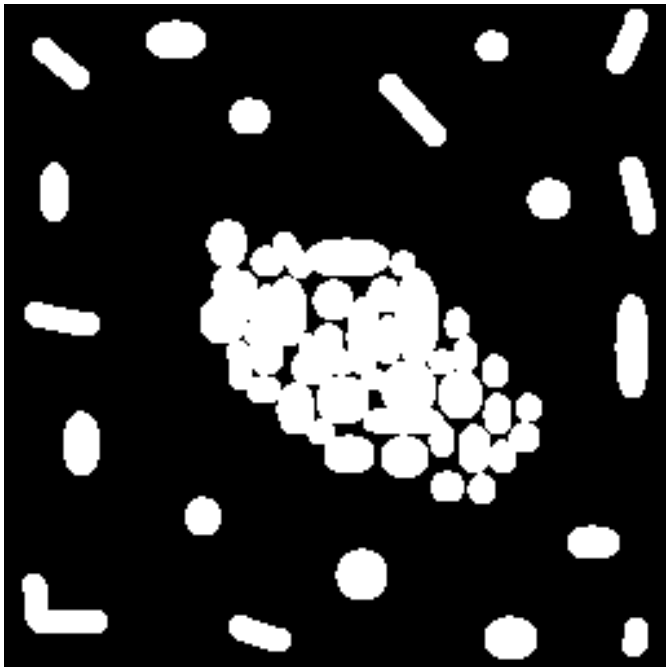
a *b* *c*

Result of multiscale top-hat transformation with small SE. (a) Near- (b) middle- and (c) far-focused images. Note that black pixels are more dense in the focused regions.

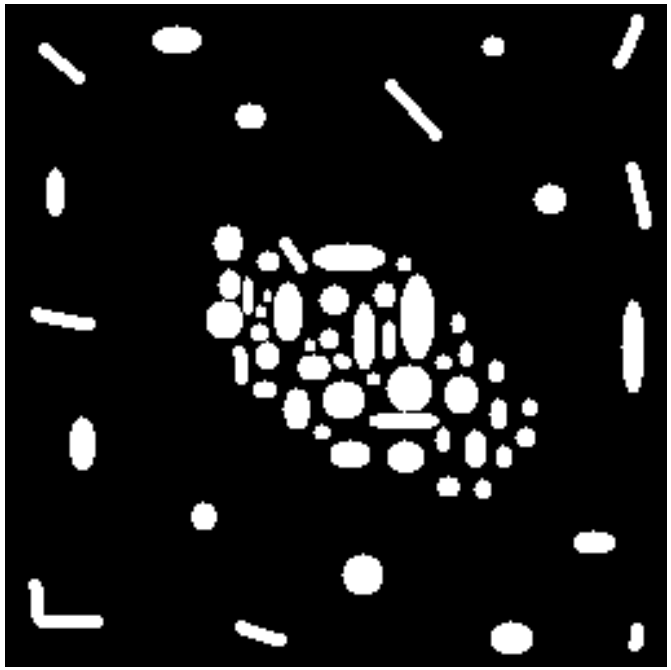
Morphological dilation

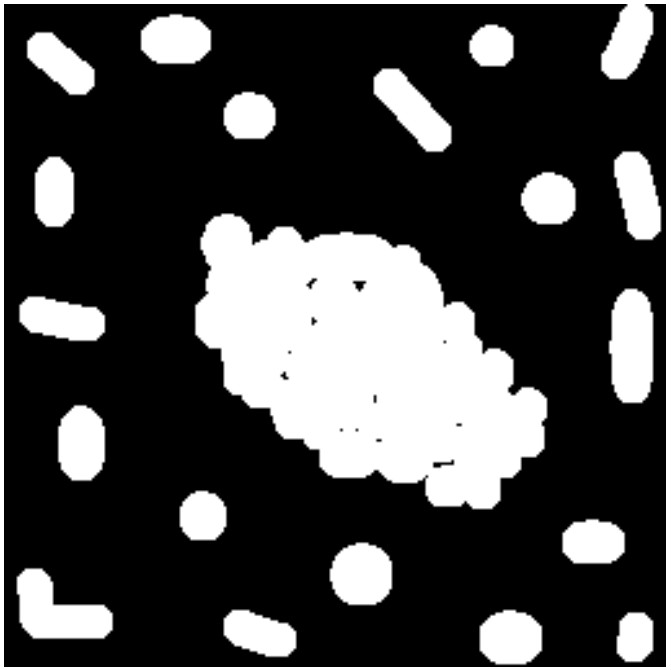


Original particles

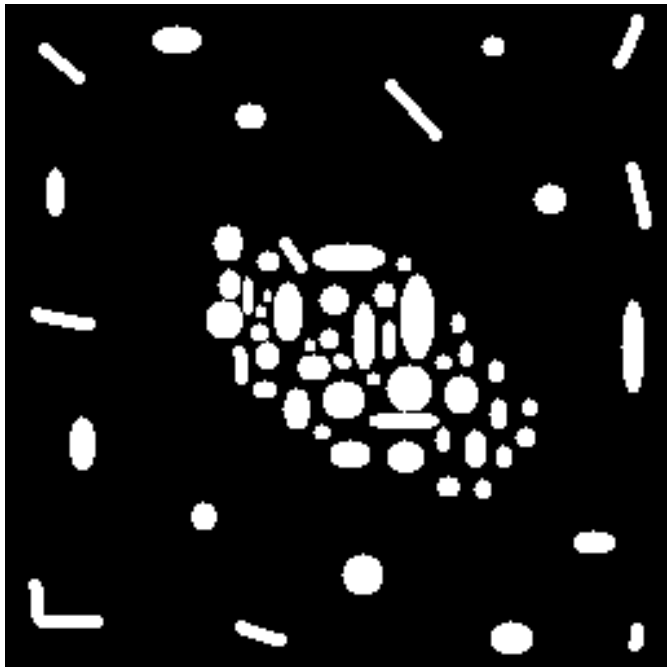


Morphological dilation

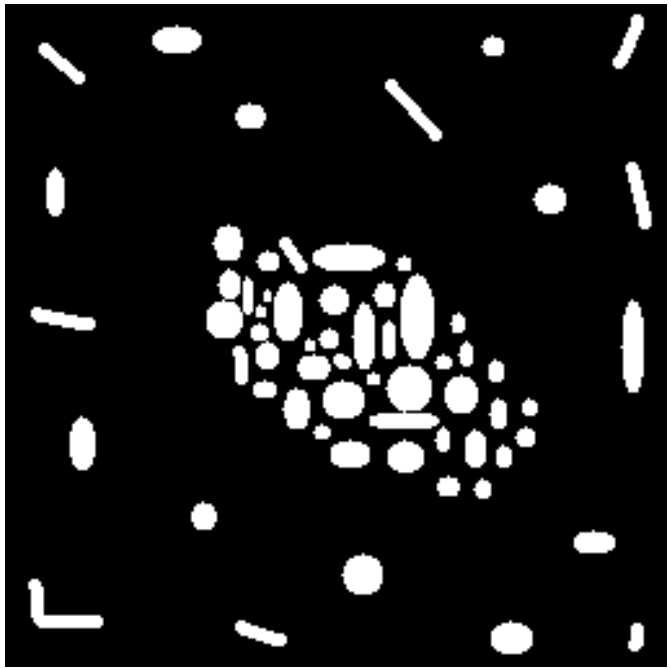


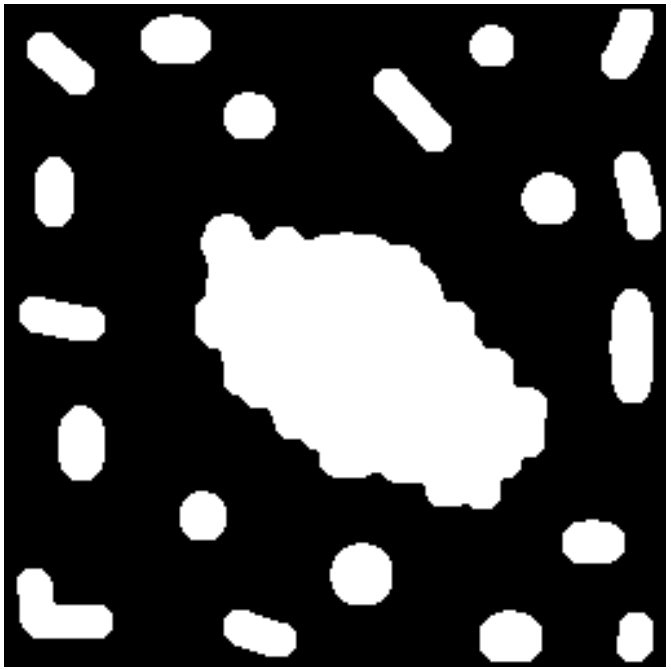


Morphological dilation

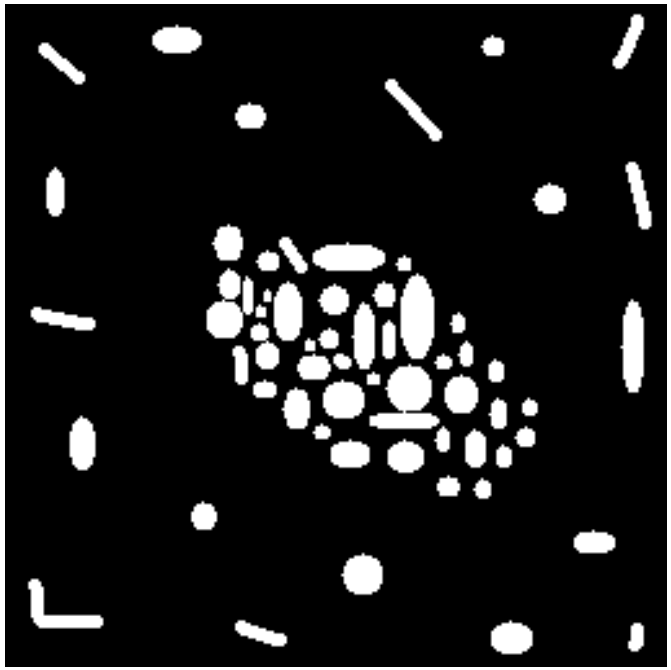


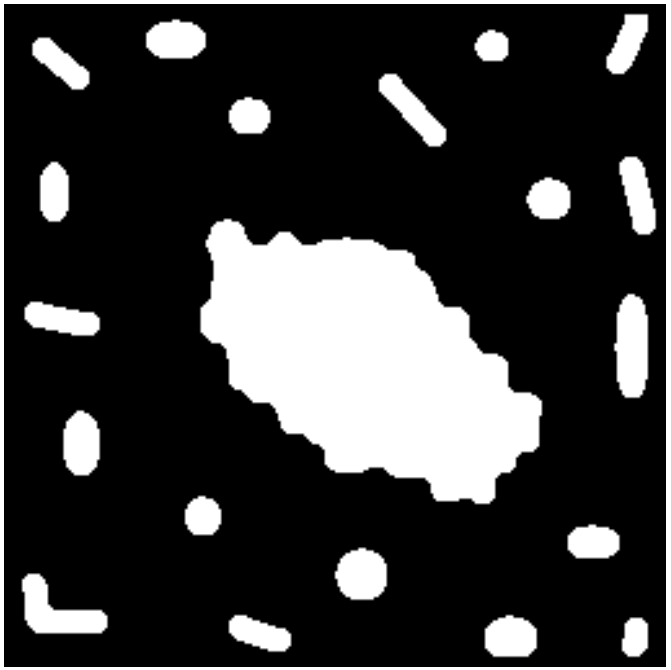
Morphological erosion



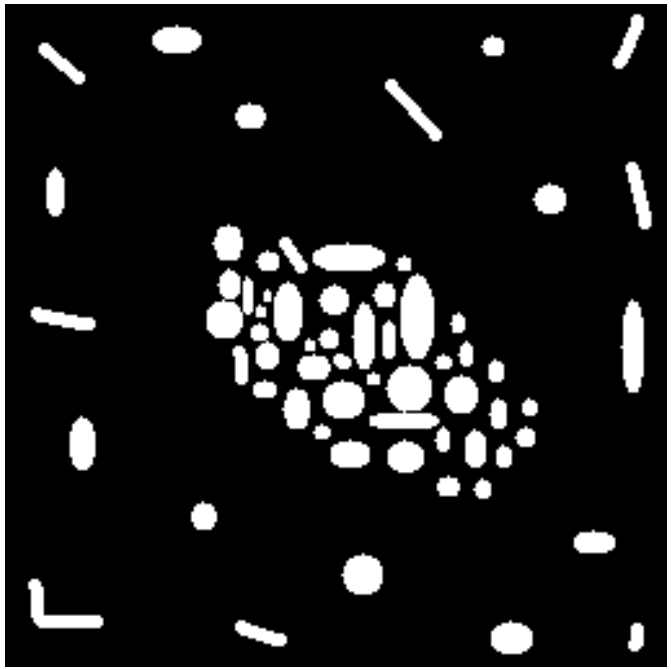


Morphological erosion



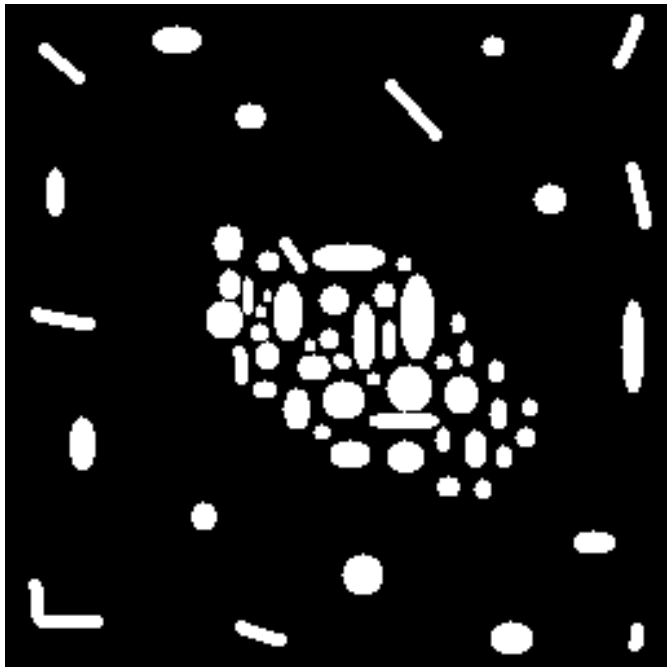


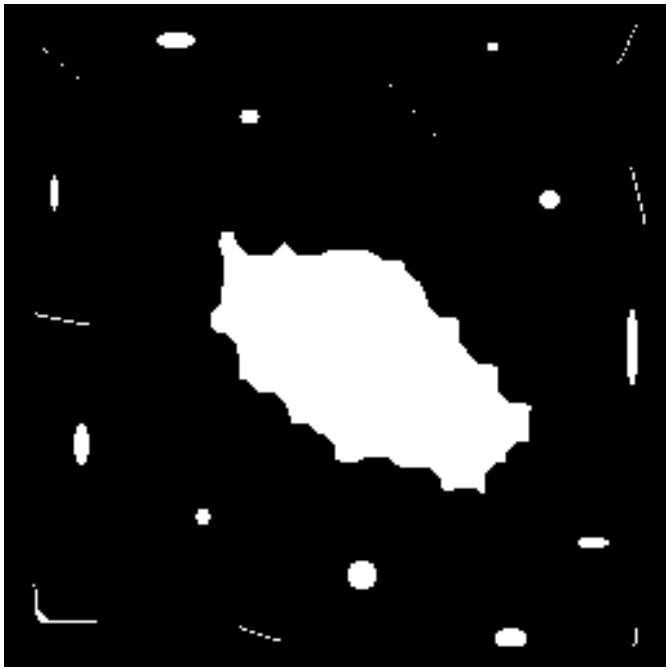
Morphological erosion



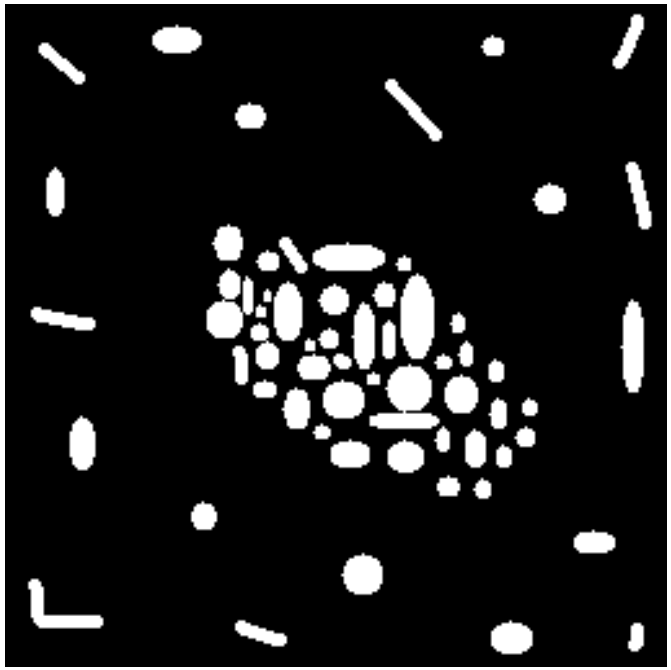
Dilation + Erosion → Closing

Morphological erosion

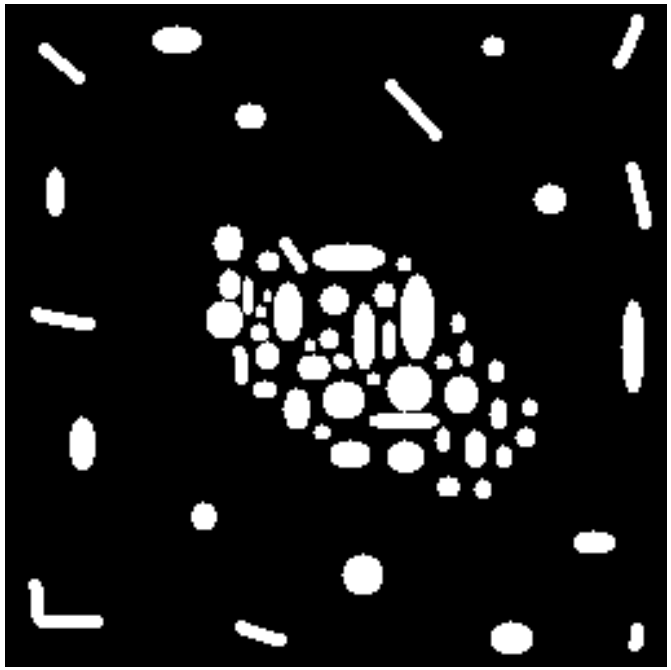


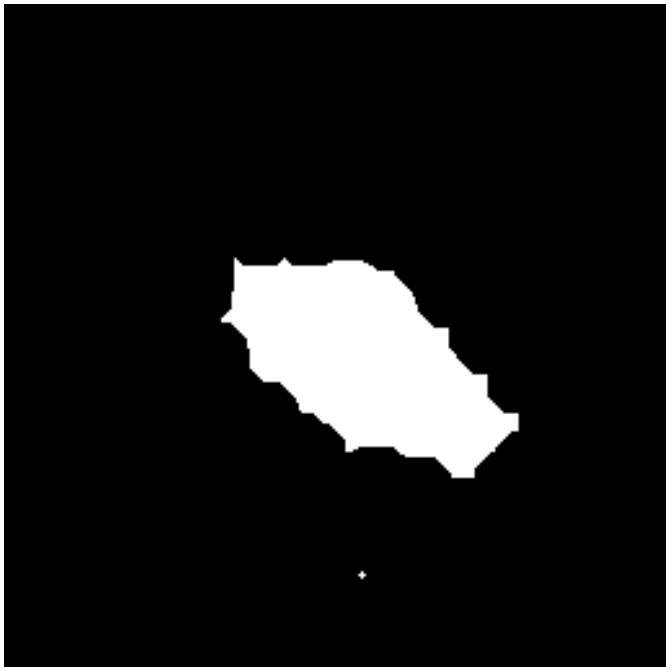


Morphological erosion

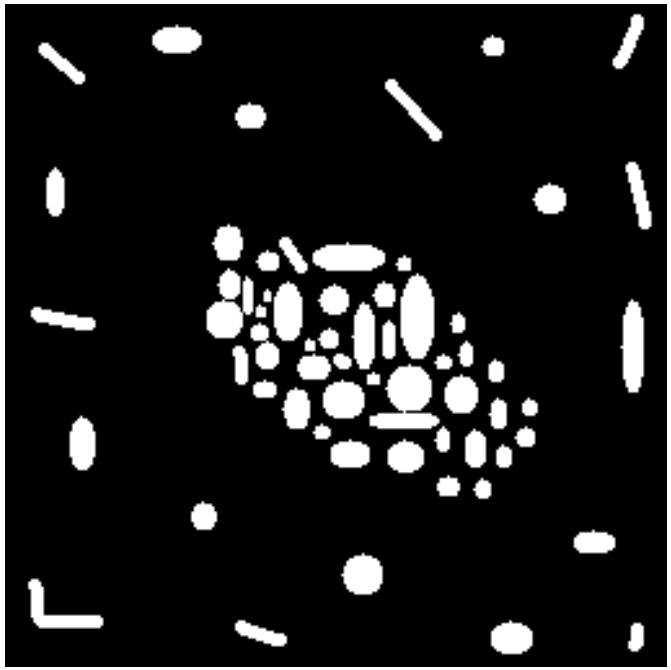


Morphological erosion

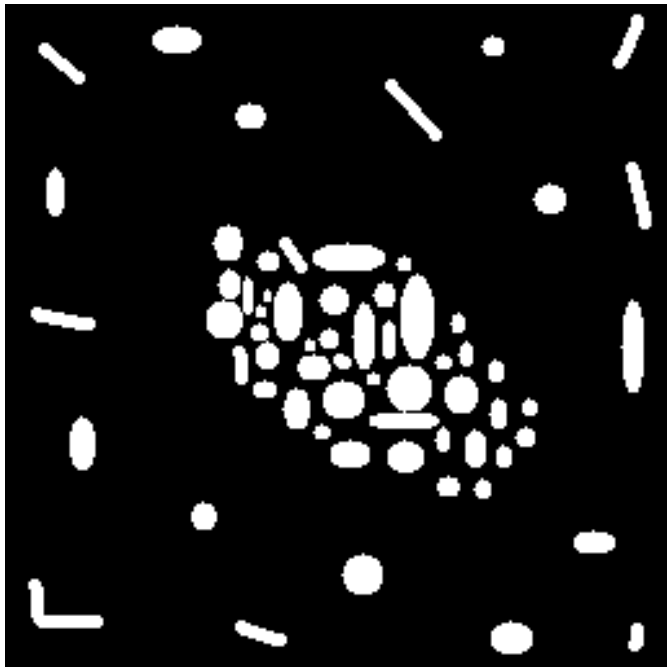


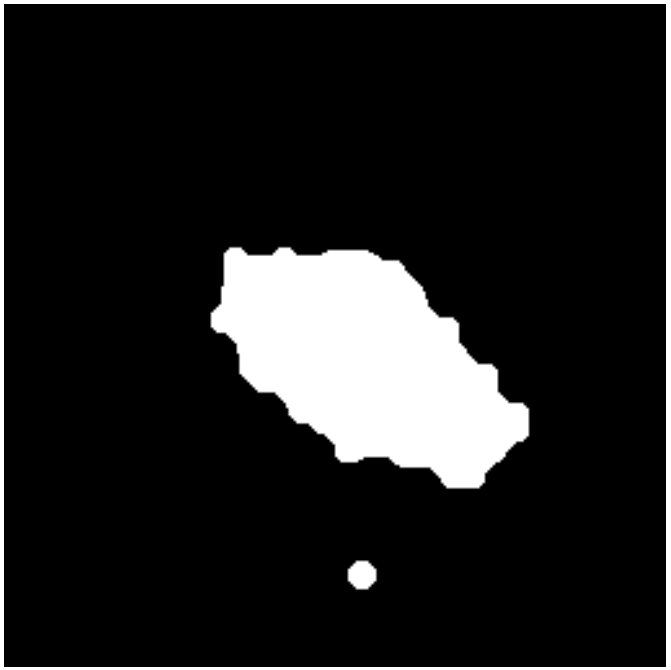


Morphological dilation

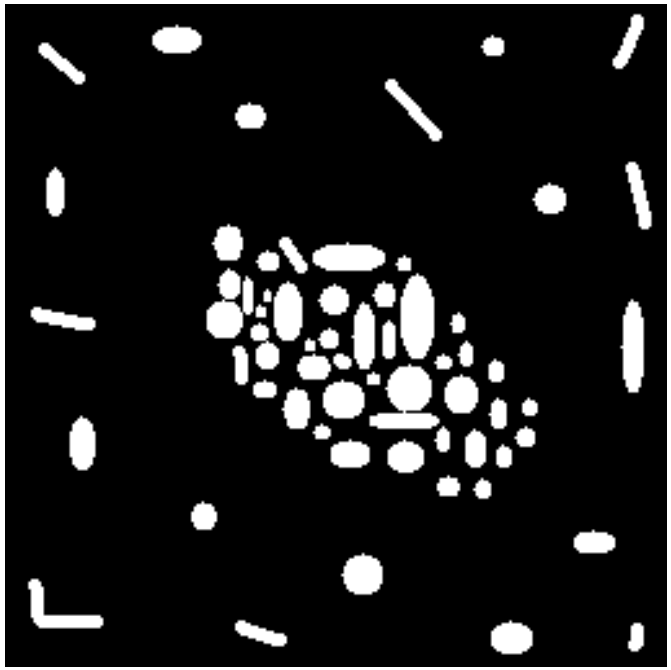


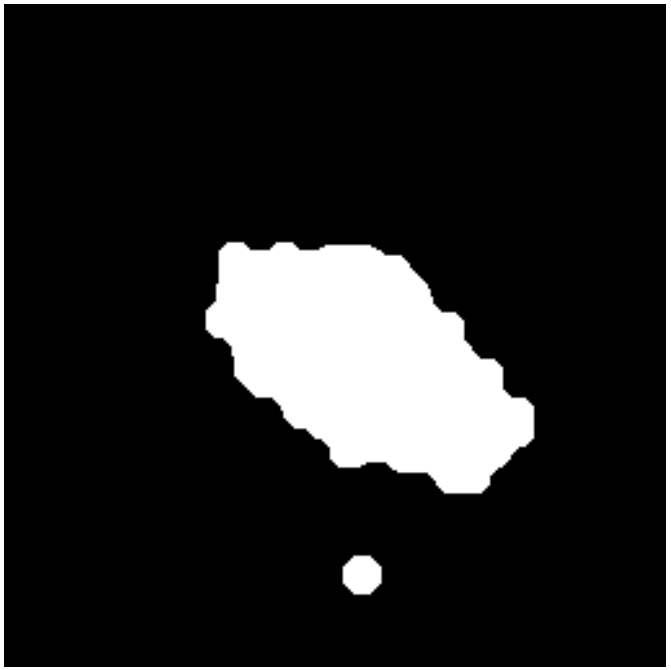
Morphological dilation





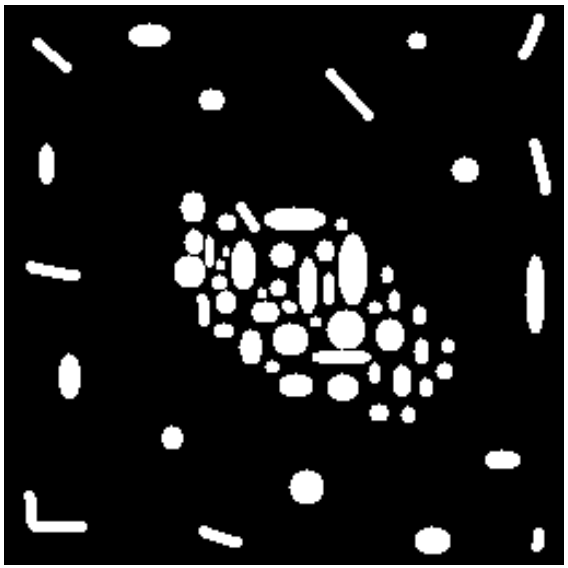
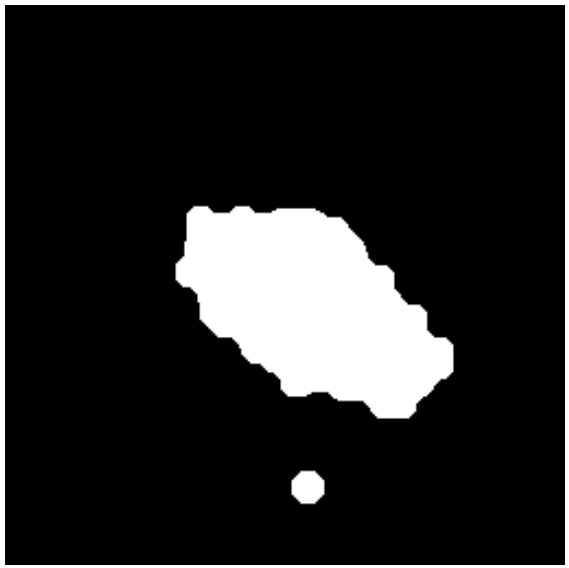
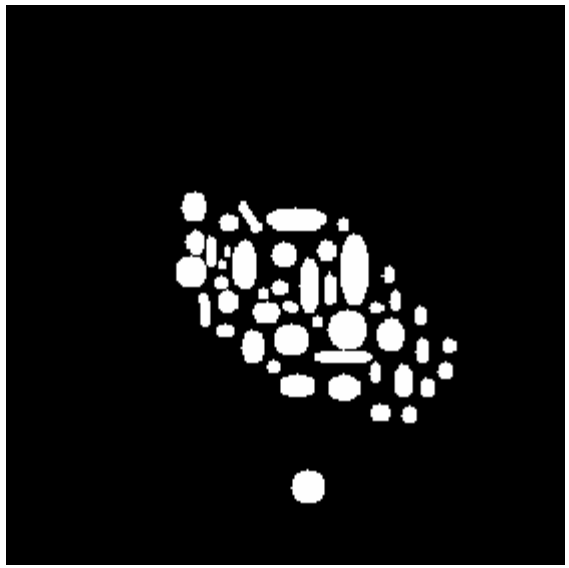
Morphological dilation





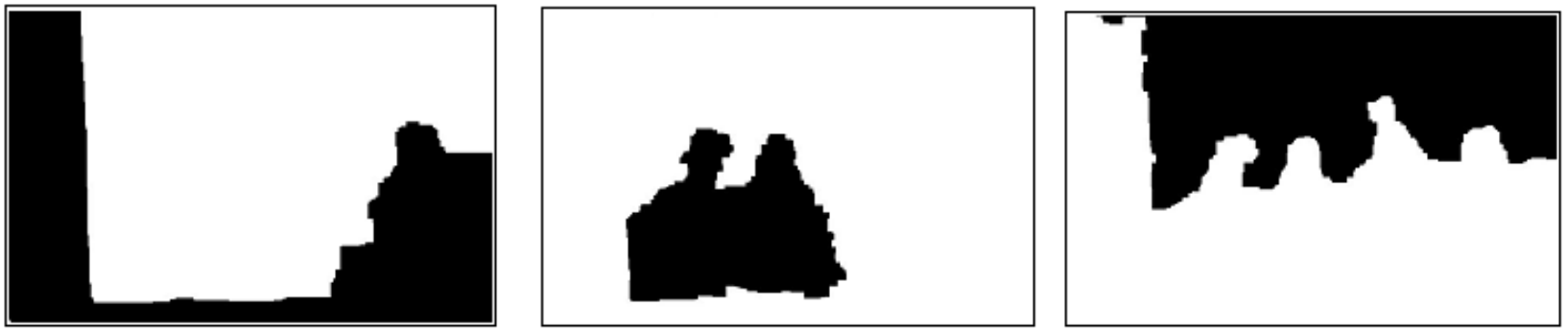
Erosion + Dilation → Opening

Region extraction

$$A \bigcap B \rightarrow C$$

Largest connected regions corresponding to focused regions



a *b* *c*

Result of sequential filter (open and close) of size n.

(a) near-focused image, (b) middle-focused image,
(c) far-focused image

Reconstruction by stitching the focused regions

a

b

Reconstructed (a) gray-level image, (b) color image

Example 1: Region-based fusion




Example 2: original images

Focus on background

Focus on foreground

Region-based Fused image

Performance Analysis

- A similarity measure is defined as

  $S(G, G') =$

  $1 - (\sum (G - G')^2)^{1/2} / ((\sum G^2)^{1/2} + (\sum G'^2)^{1/2})$

- G is the pixel-wise maximum gradient of the input images.
- G' is the pixel-wise gradient of fused image.
- More similar G and G' are, higher is the value of S, and S is 1 if $G = G'$.

Performance Analysis: Similarity between maximum gradient and fused images

Multifocused images	Region-basd approach	Block-based approach
Example 1	0.888	0.861
Example 2	0.839	0.823
Computa-tional cost	High	Low

Conclusion

- Region-based approach resembles the cut-and-paste method.
- It gives better result than the block-based method.
- But it is complex and time-consuming.
- Block-based method is fast, simple, and can be implemented easily.
- A block, being fixed shape, may include both focused and out-of focus region.

References

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Thank you