# Chapter 4: Morphological operations

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## Introduction

After binary thresholding an image to retain just the desired objects in the foreground, these images usually contain undesirable artifacts. These could small objects, objects of undesired shape, or an object separated into multiple;les ones by small fissures. Morphological operations on a binary image is useful to fix these issues. Morphological operations can also be combined to fill holes or extract object boundaries in binary images.

## The fundamental morphological operations

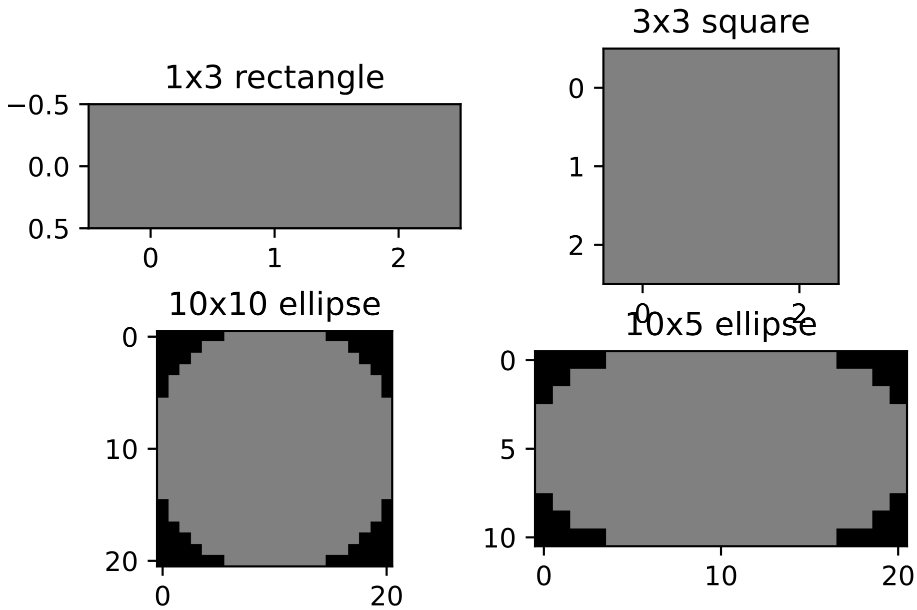
The two fundamental morphological operations are erosion and dilation. These are building blocks of number of other techniques that combine them in clever ways. Although morphological operations are applicable to both binary and grayscale images, we will focus only on binary images.

## Structuring element

The key component for a morphological operation in a structuring element. A structuring element is a identical to a kernel that we used for image smoothing. A structural element is a (small) binary image where the foreground pixels are of a desired shape. As examples, we can have rectangle or elliptical shaped structural elements:

```python
# Load the required libraries
import skimage as ski
import numpy as np
import matplotlib.pyplot as plt

# A rectangle structuring element
rect_se = ski.morphology.footprint_rectangle((1, 3))

# A square structuring element
sq_se = ski.morphology.footprint_rectangle((3, 3))

# A circular structuring element or radius 10
circle_se = ski.morphology.ellipse(10, 10)

# A elliptical strcuting element of width 10 and height 5
ellipse_se = ski.morphology.ellipse(10, 5)

# Plot the SEs
fig, ax = plt.subplots(2, 2)
ax[0, 0].imshow(rect_se, cmap = 'gray', vmin = 0, vmax = 2)
ax[0, 0].set_title('1x3 rectangle')
ax[0, 1].imshow(sq_se, cmap = 'gray', vmin = 0, vmax = 2)
ax[0, 1].set_title('3x3 square')
ax[1, 0].imshow(circle_se, cmap = 'gray', vmin = 0, vmax = 2)
ax[1, 0].set_title('10x10 ellipse')
ax[1, 1].imshow(ellipse_se, cmap = 'gray', vmin = 0, vmax = 2)
ax[1, 1].set_title('10x5 ellipse')
```

```
Text(0.5, 1.0, '10x5 ellipse')
```



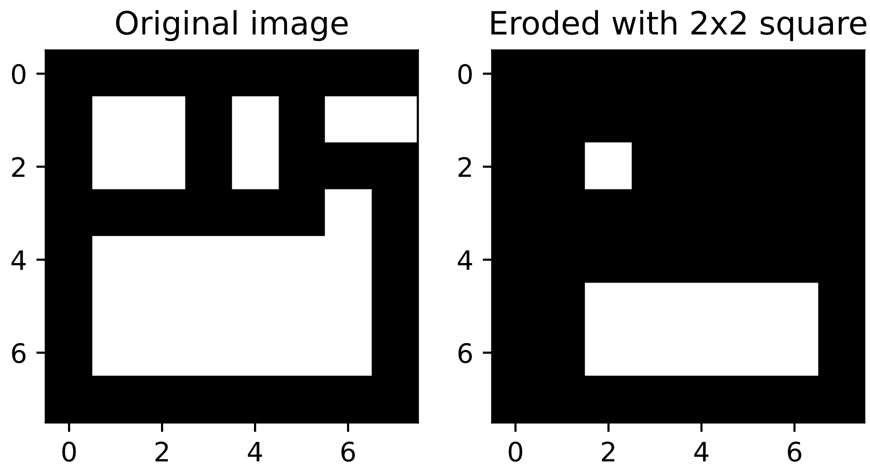

## Erosion

To erode an a binary image, we overlay the structuring element at each pixel of the input image, and the output at that pixel is set to 1 if all the pixels in the input image under the structuring element is 1. The erosion operation is useful to retain parts of the input image that "fits into" the structuring element. For example, if we are using a square structuring element 2 pixels wide, it will remove any rectangular objects in the input image that has width less than 2, and all other objects will shirk in size.

```
# Create a binary figure
img = np.array([[0, 0, 0, 0, 0, 0, 0, 0],
                [0, 1, 1, 0, 1, 0, 1, 1],
                [0, 1, 1, 0, 1, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 1, 0],
                [0, 1, 1, 1, 1, 1, 1, 0],
                [0, 1, 1, 1, 1, 1, 1, 0],
                [0, 1, 1, 1, 1, 1, 1, 0],
                [0, 0, 0, 0, 0, 0, 0, 0]])

# Create a 2x2 square structuring element
se = ski.morphology.footprint_rectangle((2, 2))

# Erode the image with the structuring element
er = ski.morphology.binary_erosion(img, se)

# Plot the figure
fig, ax = plt.subplots(1, 2)
```

```
ax[0].imshow(img, cmap = 'gray')
ax[0].set_title('Original image')
ax[1].imshow(er, cmap = 'gray')
ax[1].set_title('Eroded with 2x2 square')
```

```
Text(0.5, 1.0, 'Eroded with 2x2 square')
```



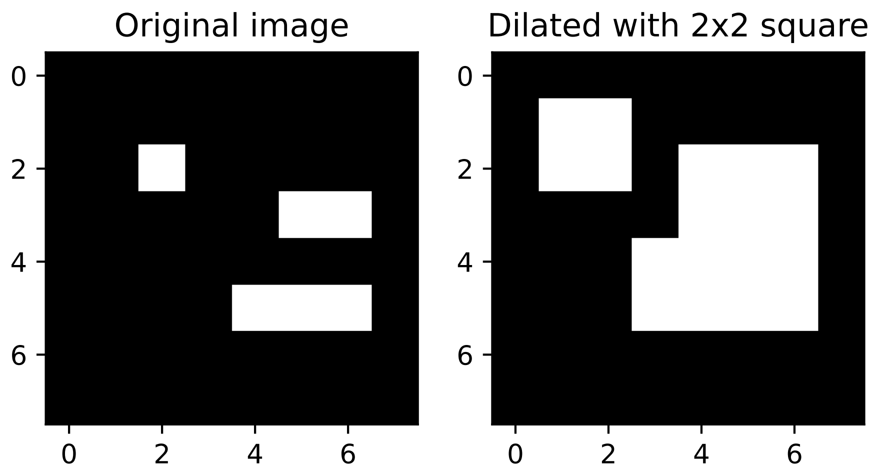

### Dilation

Dilation is the inverse of an erosion. To dilate a binary image, we overlay the structuring element at each pixel of the input image, the output at that pixel is set to 1 if any pixel in the in the input image under the structuring element is 1. The dilation operation is useful to join fissures in the input image that are smaller than the structuring element. For example, using a square structuring element 2 pixels wide will join any objects in the input image that are less than 2 pixels apart, and all other objects will expand.

```
# Create a binary image
img = np.array([[0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 1, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 1, 1, 0],
                [0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 1, 1, 1, 0],
                [0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0]])

# Create a 2x2 square structuring element
se = ski.morphology.footprint_rectangle((2, 2))

# Dilate the image with the structuring element
dil = ski.morphology.binary_dilation(img, se)
```

```
# Plot the figure
fig, ax = plt.subplots(1, 2)
ax[0].imshow(img, cmap = 'gray')
ax[0].set_title('Original image')
ax[1].imshow(dil, cmap = 'gray')
ax[1].set_title('Dilated with 2x2 square')
```

```
Text(0.5, 1.0, 'Dilated with 2x2 square')
```




# Combining erosion and dilation

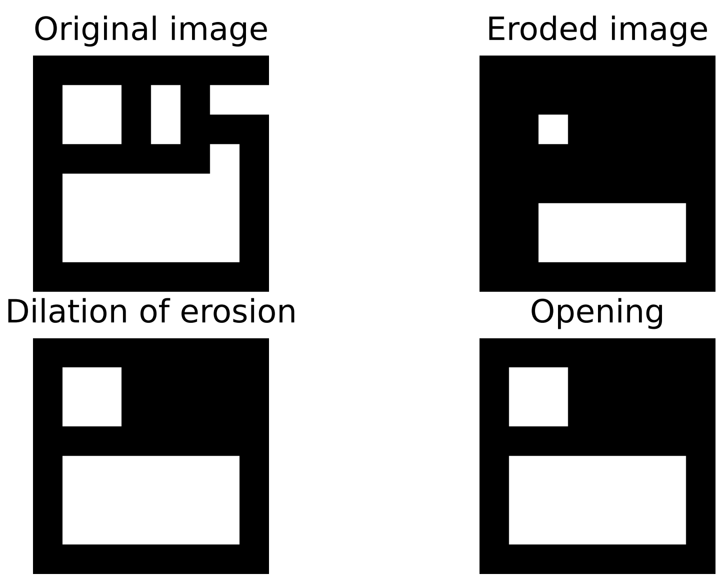
Erosion and Dilation operations can be combined to create higher order operations. Morphological opening and closing are preforming an erosion and dilation consecutively. These operations in effect restore the "damage" done by the other operation.

## Morphological opening

Morphological opening first erodes an image and then dilates the eroded image. As we have seen eroding an image removes objects smaller than the structuring elements, and makes all other objects in the input image smaller. Dilating the eroded image restores these smaller objects by making them bigger. Importantly, the operations that were lost in the erosion are not restored. In essence, we remove all objects smaller than the structuring element and all other objects are restored.

```
# Create a binary image
img = np.array([[0, 0, 0, 0, 0, 0, 0, 0],
                [0, 1, 1, 0, 1, 0, 1, 1],
                [0, 1, 1, 0, 1, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 1, 0],
                [0, 1, 1, 1, 1, 1, 1, 0],
```

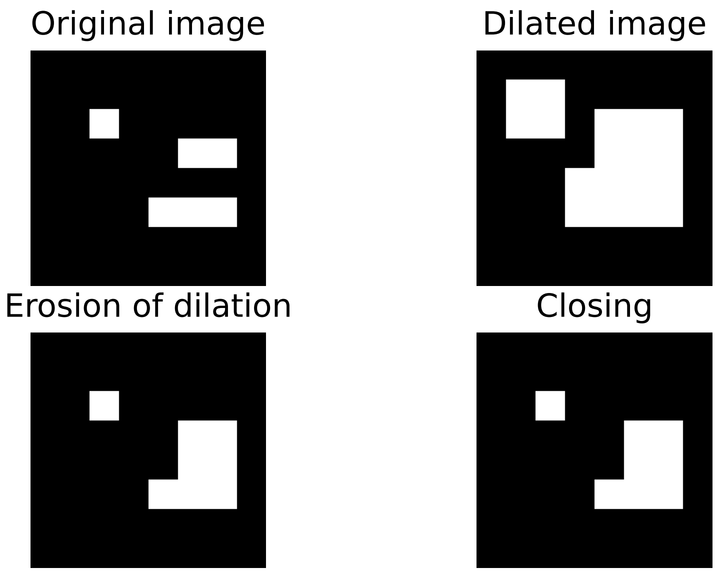
```
                 [0, 1, 1, 1, 1, 1, 1, 0],
                 [0, 1, 1, 1, 1, 1, 1, 0],
                 [0, 0, 0, 0, 0, 0, 0, 0]])

# Create a 2x2 square structuring element
se = ski.morphology.footprint_rectangle((2, 2))

# Erode the input image
er = ski.morphology.binary_erosion(img, se)
# Dilate the eroded image
dil_er = ski.morphology.binary_dilation(er, se)

# The above two steps can be done in one step
opening = ski.morphology.opening(img, se)

# Plot the image
fig, ax = plt.subplots(2, 2)
ax[0, 0].imshow(img, cmap = 'gray')
ax[0, 0].set_title('Original image')
ax[0, 1].imshow(er, cmap = 'gray')
ax[0, 1].set_title('Eroded image')
ax[1, 0].imshow(dil_er, cmap = 'gray')
ax[1, 0].set_title('Dilation of erosion')
ax[1, 1].imshow(opening, cmap = 'gray')
ax[1, 1].set_title('Opening')
for a in ax.flatten():
    a.set_axis_off()
```



## Morphological closing

Morphological closing first dilates an image and then erodes the dilated image. Dilating an image makes all objects bigger and objects that closer than the structuring element are joined into one, and makes all other objects larger. Eroding a dilated image restores the larger objects by making them smaller. Importantly, the objects that were merged by the dilation will remain merges. In effect, we connect objects that are closer than the structuring element and all other objects are restored.

```
# Create a binary image
img = np.array([[0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 1, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 1, 1, 0],
                [0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 1, 1, 1, 0],
                [0, 0, 0, 0, 0, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 0, 0]])

# Create a 2x2 square structuring element
se = ski.morphology.footprint_rectangle((2, 2))

# Dilate the input image
dil = ski.morphology.binary_dilation(img, se)
# Erode the dilated image
er_dil = ski.morphology.binary_erosion(dil, se)

# The above two steps can be done in one step
closing = ski.morphology.closing(img, se)

# Plot the image
fig, ax = plt.subplots(2, 2)
ax[0, 0].imshow(img, cmap = 'gray')
ax[0, 0].set_title('Original image')
ax[0, 1].imshow(dil, cmap = 'gray')
ax[0, 1].set_title('Dilated image')
ax[1, 0].imshow(er_dil, cmap = 'gray')
ax[1, 0].set_title('Erosion of dilation')
ax[1, 1].imshow(closing, cmap = 'gray')
ax[1, 1].set_title('Closing')
for a in ax.flatten():
    a.set_axis_off()
```




Note that for both opening and closing, the final image ins not a prefect reconstruction of the input image.

# Iterative erosion and dilation

We can get to further higher order operation by iteratively applying these operations. There are several of the, but let us look at three that come in very handy when analyzing biological samples.

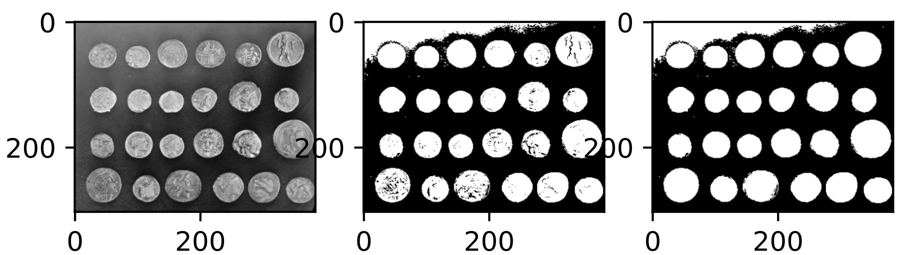
## Hole filling

As the name suggests, this fills holes in in binary images. Holes in a binary image are background pixels that are completely surrounded by foreground pixels. A fife filling converts these background pixels into foreground ound pixels.

```
# Load the cell images
# img = ski.io.imread("data/F01_202w1.TIF")
img = ski.data.coins()

# Covert it into a binary image with otsu thresholding
otsu_thresh = ski.filters.threshold_otsu(img)
img_otsu = img > otsu_thresh

border_img = np.ones(img.shape, dtype = bool)
border_img[1:-1, 1:-1] = 0
print(~img_otsu)

hole_filled = ski.morphology.reconstruction((~img_otsu) & border_img, ~img_otsu)
```

```
hole_filled = ~hole_filled.astype(bool)

fig, ax = plt.subplots(1, 3)
ax[0].imshow(img, cmap = 'gray')
ax[1].imshow(img_otsu, cmap = 'gray')
ax[2].imshow(hole_filled, cmap = 'gray')
```

```
[[ True False False ...  True  True  True]
 [ True False False ...  True  True  True]
 [False False False ...  True  True  True]
 ...
 [ True  True  True ...  True  True  True]
 [ True  True  True ...  True  True  True]
 [ True  True  True ...  True  True  True]]
```



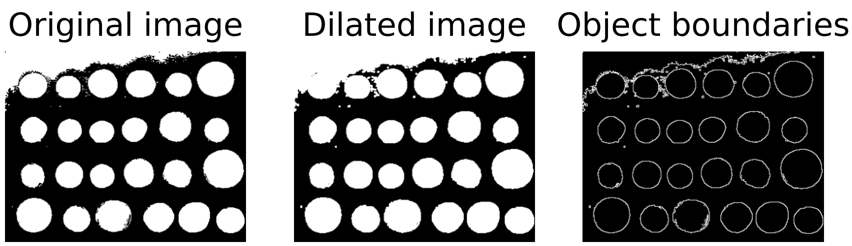

### Border extraction We can get the border of objects by dilating an image

with a 3x3 square structuring element to make all objects in the image one pixel larger. We can them subtract the original image from the dilated image to retain just the border pixels.

```
img = ski.data.coins()

# create SE and dilate
se = ski.morphology.footprint_rectangle((3, 3))
dil = ski.morphology.binary_dilation(hole_filled, se)

# subtract from the dilated image
border = dil ^ hole_filled
print(hole_filled.dtype)

fig, ax = plt.subplots(1, 3)
ax[0].imshow(hole_filled, cmap='gray')
ax[0].set_title('Original image')
ax[1].imshow(dil, cmap='gray')
ax[1].set_title('Dilated image')
ax[2].imshow(border, cmap='gray')
```

```
ax[2].set_title('Object boundaries')
for a in ax:
    a.set_axis_off()
```

```
bool
```



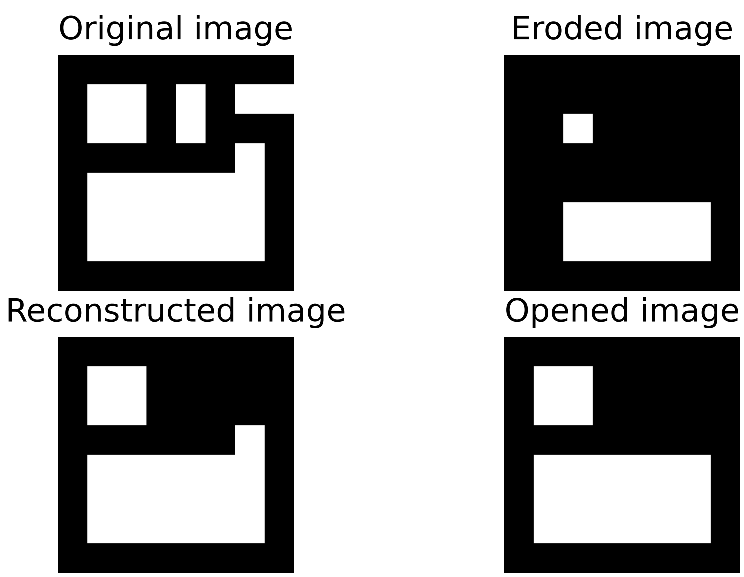

## Morphological reconstruction

As we have seen opening changes the shape of the objects in the input image, and these can be quite problematic when we need to preserve the object shapes. Morphological reconstruction is a way to preserve the shape of the of the objects. It takes a input tow binary images a the input binary image (usually referred to as the mask image) and a seed image (sometimes referred toa the marker image). In the fist stem the seed image in expanded by dilation. However this dilation is contained by the mask image, such that the dilation does not expand to any pixels that is not a foreground pixel in the mask image. This process is repeated iteratively until the there is no changes.

We can use the inbuilt function to accomplish this.

```
# Create a binary image
img = np.array([[0, 0, 0, 0, 0, 0, 0, 0],
                [0, 1, 1, 0, 1, 0, 1, 1],
                [0, 1, 1, 0, 1, 0, 0, 0],
                [0, 0, 0, 0, 0, 0, 1, 0],
                [0, 1, 1, 1, 1, 1, 1, 0],
                [0, 1, 1, 1, 1, 1, 1, 0],
                [0, 1, 1, 1, 1, 1, 1, 0],
                [0, 0, 0, 0, 0, 0, 0, 0]])

# Create a structuring element
se = ski.morphology.footprint_rectangle((2, 2))

# Erode the original image to use as seed
er = ski.morphology.binary_erosion(img, se)

# Reconstruct starting from the eroded image
# and using the original image as mask
reconst = ski.morphology.reconstruction(er, img)
```

```python
# Openeing of the orgiginal image for comparison
opening = ski.morphology.opening(img, se)

# Plot the images
fig, ax = plt.subplots(2, 2)
ax[0, 0].imshow(img, cmap='gray')
ax[0, 0].set_title('Original image')
ax[0, 1].imshow(er, cmap='gray')
ax[0, 1].set_title('Eroded image')
ax[1, 0].imshow(reconst, cmap='gray')
ax[1, 0].set_title('Reconstructed image')
ax[1, 1].imshow(opening, cmap='gray')
ax[1, 1].set_title('Opened image')
for a in ax.flatten():
    a.set_axis_off()
```




### Skelitionization