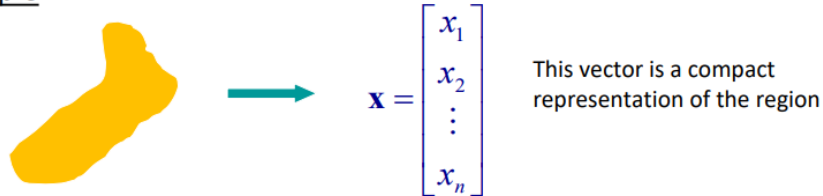


6.1 Shape descriptors

The main objective of region description is to obtain a mathematical representation of a segmented region from an image consisting of a vector of features $\mathbf{x} = [x_1, \dots, x_n]$.

Example:



In this notebook we will see a branch of region description called **shape analysis**. Shape analysis aims to construct this feature vector using only shape features (e.g., size, perimeter, circularity or compactness).

Depending on the application, it could be needed that the used descriptor be **invariant** to the position in the image in which the regions appears, its orientation, and/or its size (scale). Some examples:



Position invariance



Orientation invariance



Scale invariance

This notebook **covers simple shape descriptors of regions** based on their area, perimeter, minimal bounding-box, etc (sections 6.1.1 and 6.1.2). We will also study **if these descriptors are invariant to position, orientation and size** (section 6.1.3). Let's go!

Problem context - Number-plate recognition

So here we are again! UMA called for us to join a team working on their parking access system. This time, they want to upgrade their obsolete number-plate detection algorithm by including better and more efficient methods.



Here is where our work starts, we are going to **apply shape analysis to each of the characters** that can appear on a license plate, that is, numbers from 0 to 9, and letters in the alphabet. The idea is to **produce a unique feature vector** for each character that could appear on a plate (e.g. \mathbf{x}^0 , \mathbf{x}^1 , ..., \mathbf{x}^A , \mathbf{x}^B , etc.) so it could be later used to **train an automatic classification system** (we will see this in the next chapter!).

```
In [1]: import numpy as np
import cv2
import matplotlib.pyplot as plt
import matplotlib
matplotlib.rcParams['figure.figsize'] = (15.0, 8.0)

images_path = './images/'
```

Initial data

UMA's parking security team have sent us some segmented plate characters captured by their camera in the parking. They have binarized and cropped these images, providing us with regions representing such characters as white pixels. These cropped images are

`region_0.png` (region with a zero), `region_6.png` (region with a six),
`region_B.png` (region with a B), and `region_J.png` (region with a J).

Let's visualize them!

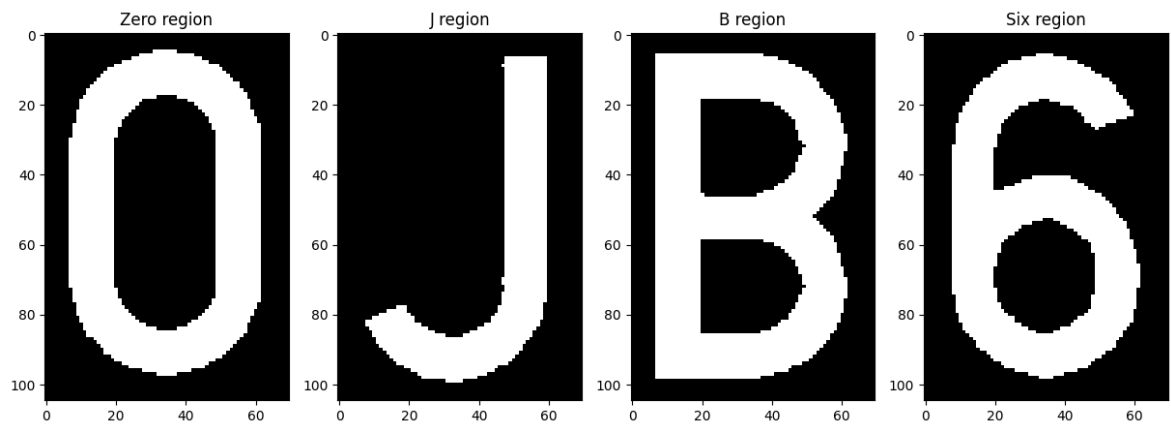
```
In [2]: # Read the images
zero = cv2.imread(images_path + 'region_0.png',0)
J = cv2.imread(images_path + 'region_J.png',0)
B = cv2.imread(images_path + 'region_B.png',0)
six = cv2.imread(images_path + 'region_6.png',0)

# And show them!
plt.subplot(141)
plt.imshow(zero, cmap='gray')
plt.title('Zero region')

plt.subplot(142)
plt.imshow(J, cmap='gray')
plt.title('J region')

plt.subplot(143)
plt.imshow(B, cmap='gray')
plt.title('B region')

plt.subplot(144)
plt.imshow(six, cmap='gray')
plt.title('Six region');
```



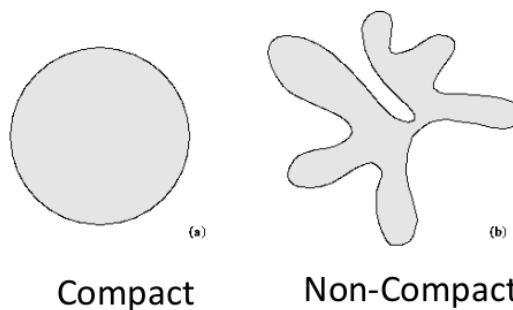
6.1.1 Compactness

The first feature we are going to work with is **compactness**:

$$\text{compactness} = \frac{\text{area}}{\text{perimeter}^2}$$

$\backslash[5pt]$

As you can see, this feature associates the area with the perimeter of a region. Informally, it tells how *rounded* and *closed* is a region. The most compact shape is the circle, with **compactness** = $1/(4\pi)$.



OpenCV pill

OpenCV uses contours for analysing shapes. A contour is a list of points that defines a region. We can obtain the contours of a region using `cv2.findContours()`.

ASSIGNMENT 1: Computing compactness

What to do? Complete the function bellow, named `compactness()`, which computes the compactness of an input region.

For that, we are going to use the `cv2.findContours()` function, which takes as input:

- A binary image (containing the region as white pixels).
- Contour retrieval mode, it can be:

- `RETR_EXTERNAL` : only returns the external contour
 - `RETR_LIST` : returns all contours (e.g. the character 0 would contain two contours: external and internal)
 - `RETR_CCOMP` : returns all contours and organize them in a two-level hierarchy. At the top level, there are external boundaries of the components. At the second level, there are boundaries of the holes.
- Method: controls how many points of the contours are being stored, this is for optimization purposes.
 - `CHAIN_APPROX_NONE` : stores absolutely all the contour points.
 - `CHAIN_APPROX_SIMPLE` : compresses horizontal, vertical, and diagonal segments and leaves only their end points.
 - `CHAIN_APPROX_TC89_L1` : applies an optimization algorithm.

And returns:

- a list containing the contours,
- and a list containing information about the image topology. It has as many elements as the number of contours.

For simplicity, we are going to take into account **only the external boundary** (as if the regions have not holes), so the second output is not relevant.

Having the contours, you can obtain the **area** and the **perimeter** of the region through `cv2.contourArea()` and `cv2.arcLength()`. Both functions take the contours of the region as input.

Note: Use `cv2.RETR_EXTERNAL` and `cv2.CHAIN_APPROX_NONE`.

```
In [3]: # Assignment 1
def compactness(region):
    """ Compute the compactness of a region.

    Args:
        region: Binary image

    Returns:
        compactness: Compactness of region (between 0 and 1/4pi)
    """
    plt.imshow(region, cmap='gray')
    plt.show()
    # Get external contour
    contours, _ = cv2.findContours(region, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_NONE)
    cnt = contours[0]

    img_contours = np.zeros(region.shape)
    # draw the contours on the empty image
    cv2.drawContours(img_contours, contours, -1, (255,255,255), 1)
    plt.imshow(img_contours, cmap='gray')
    plt.show()

    # Calcule area
```

```

area = cv2.contourArea(cnt)

# Calcule perimeter
perimeter = cv2.arcLength(cnt,True)

print("Area:",area)
print("Perimeter:", perimeter)

# Calcule compactness
compactness = area/(perimeter**2)

return compactness

```

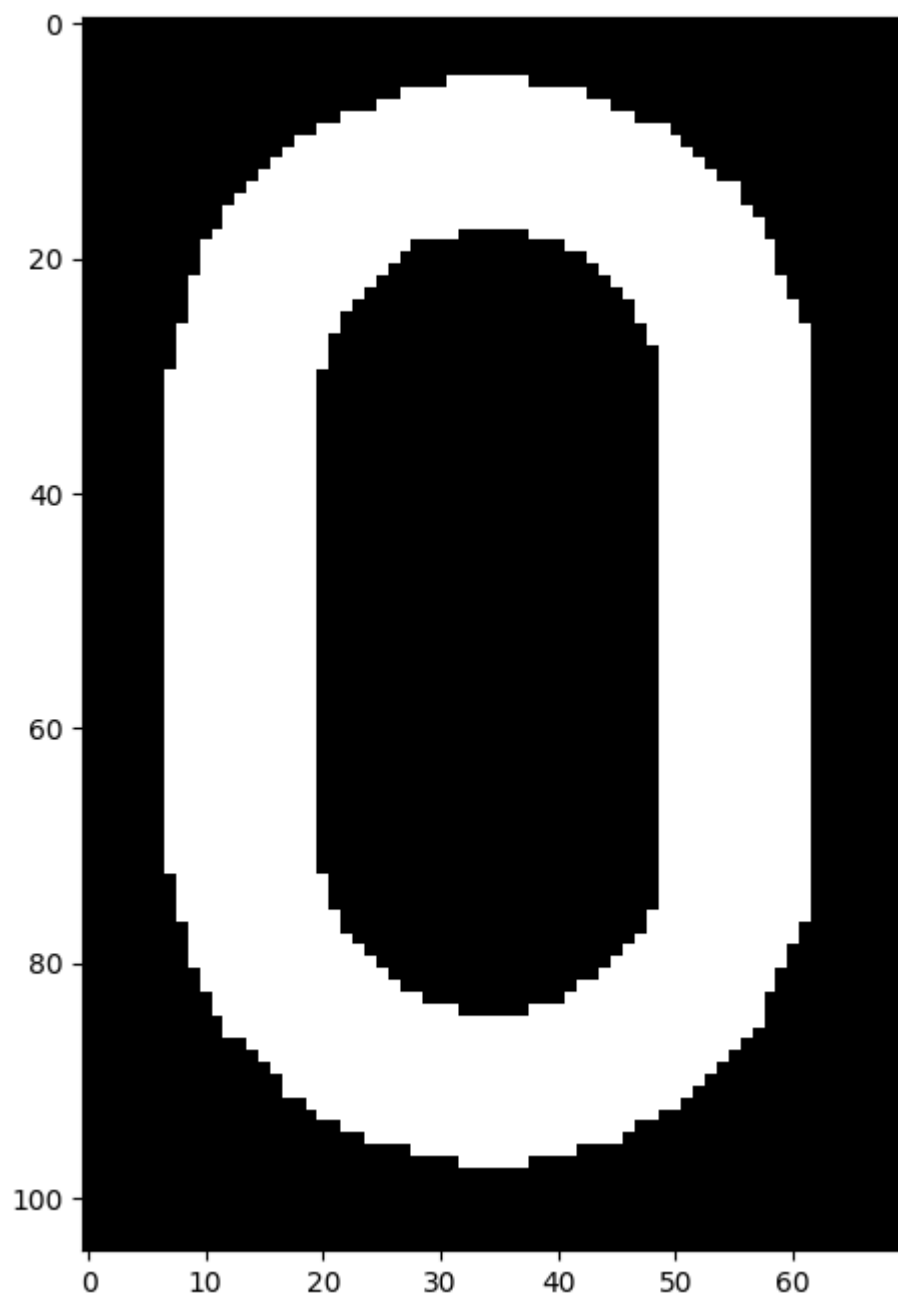
You can use next code to **test if the results are right**:

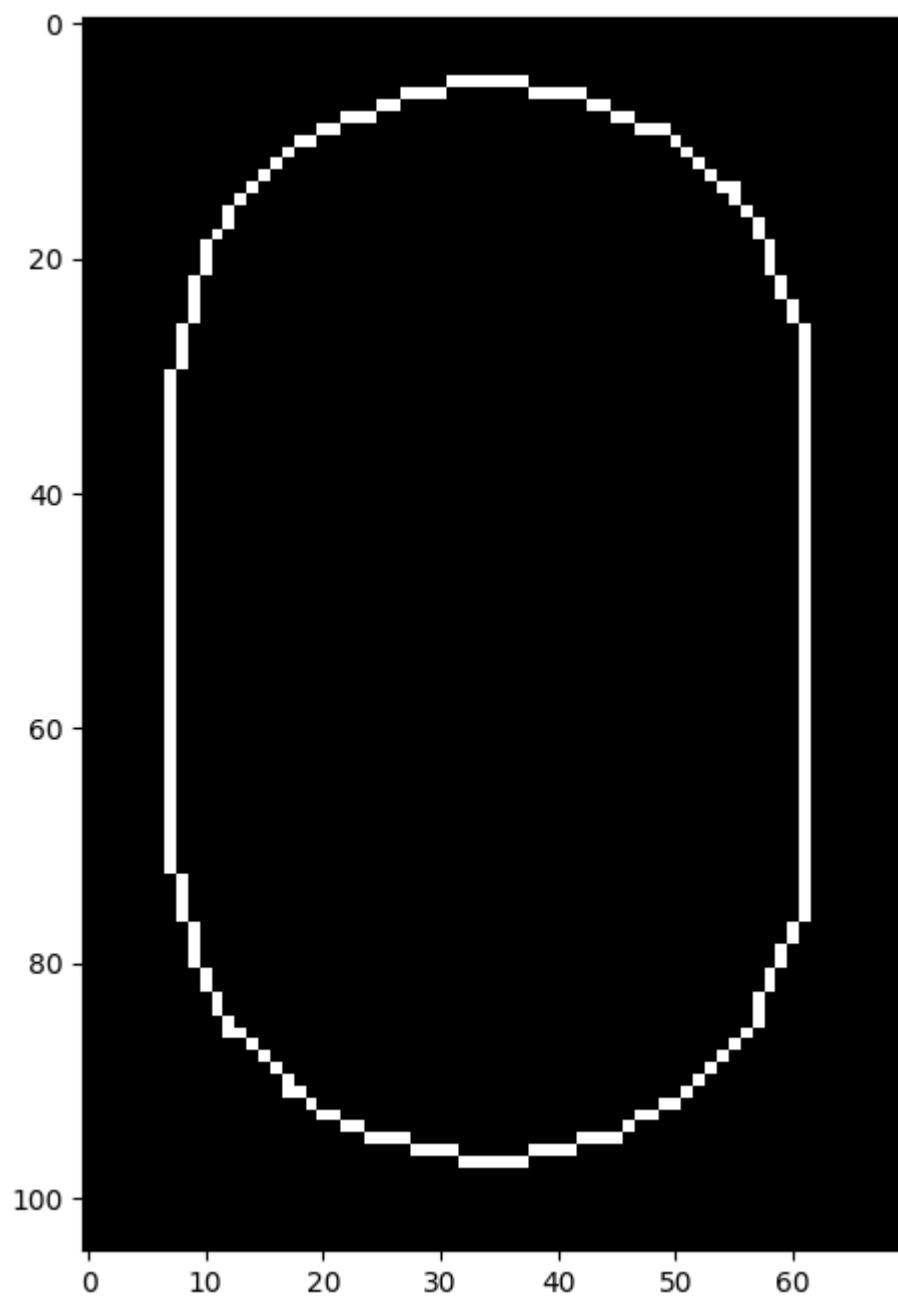
```

In [4]: # Read the images
zero = cv2.imread(images_path + 'region_0.png',0)
J = cv2.imread(images_path + 'region_J.png',0)
B = cv2.imread(images_path + 'region_B.png',0)
six = cv2.imread(images_path + 'region_6.png',0)

# And show their compactness!
print(" Compactness of 0: ", round(compactness(zero),5), "\n",
      "Compactness of J: ", round(compactness(J),5), "\n",
      "Compactness of B: ", round(compactness(B),5), "\n",
      "Compactness of 6: ", round(compactness(six),5))

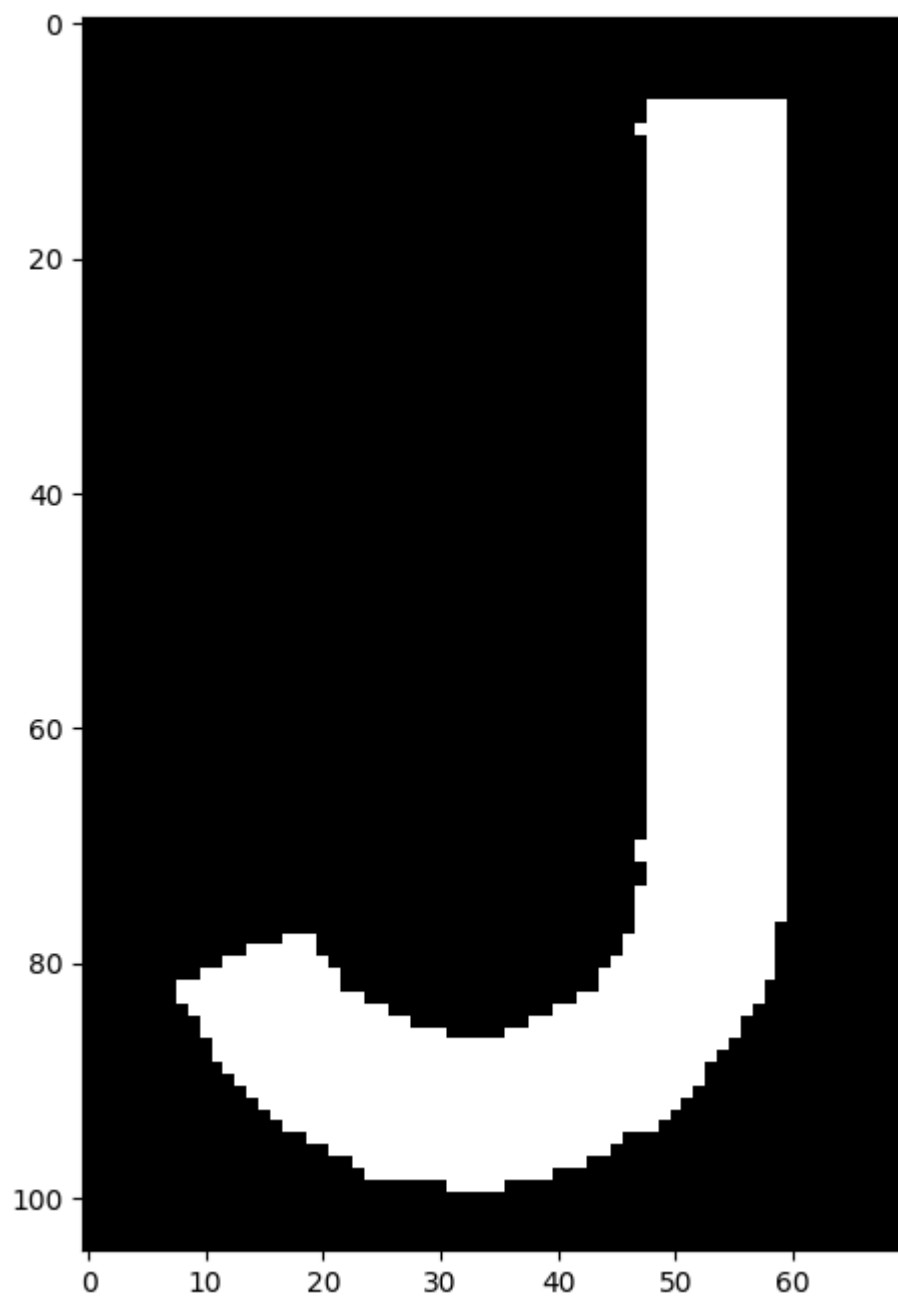
```

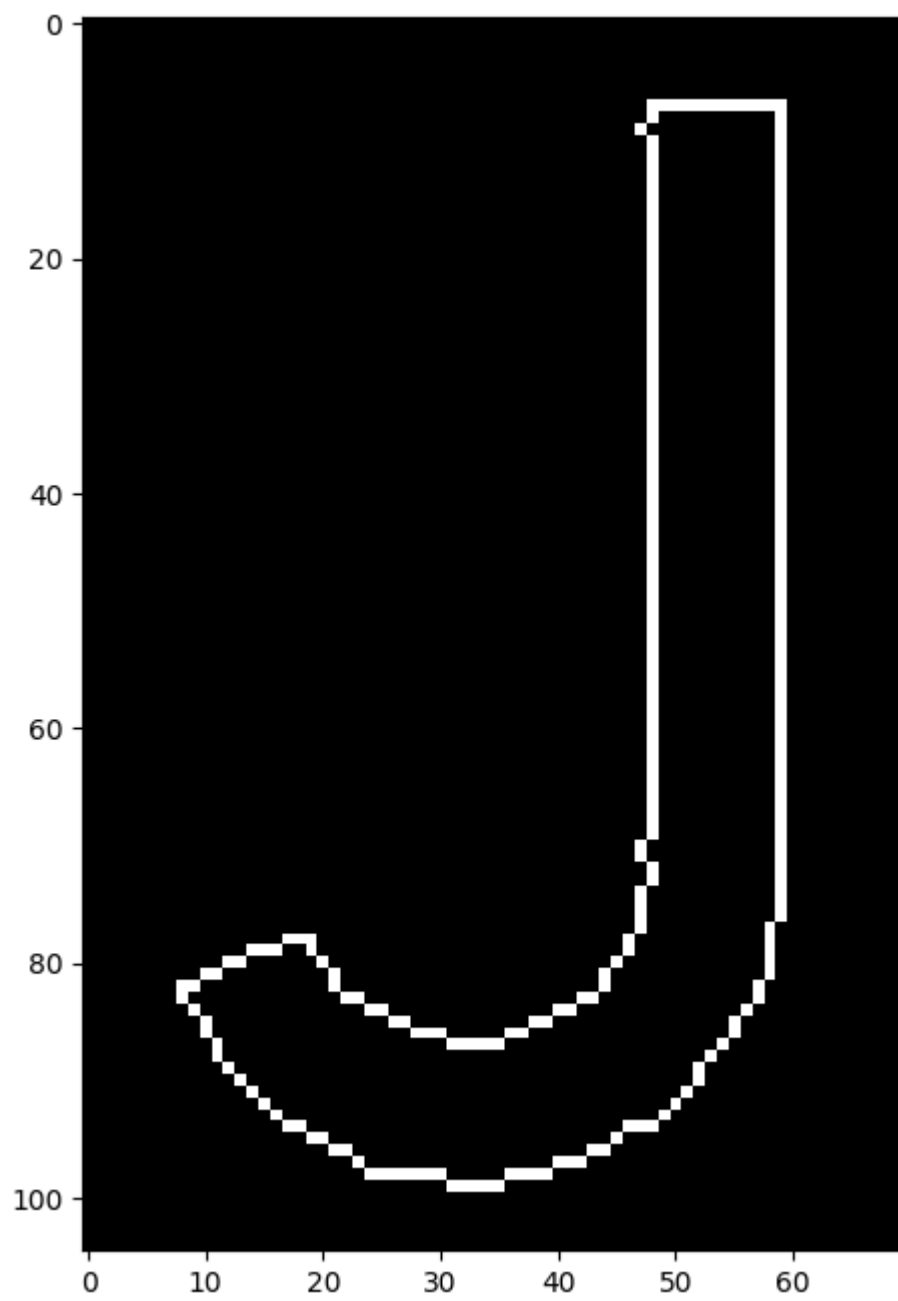




Area: 4307.0

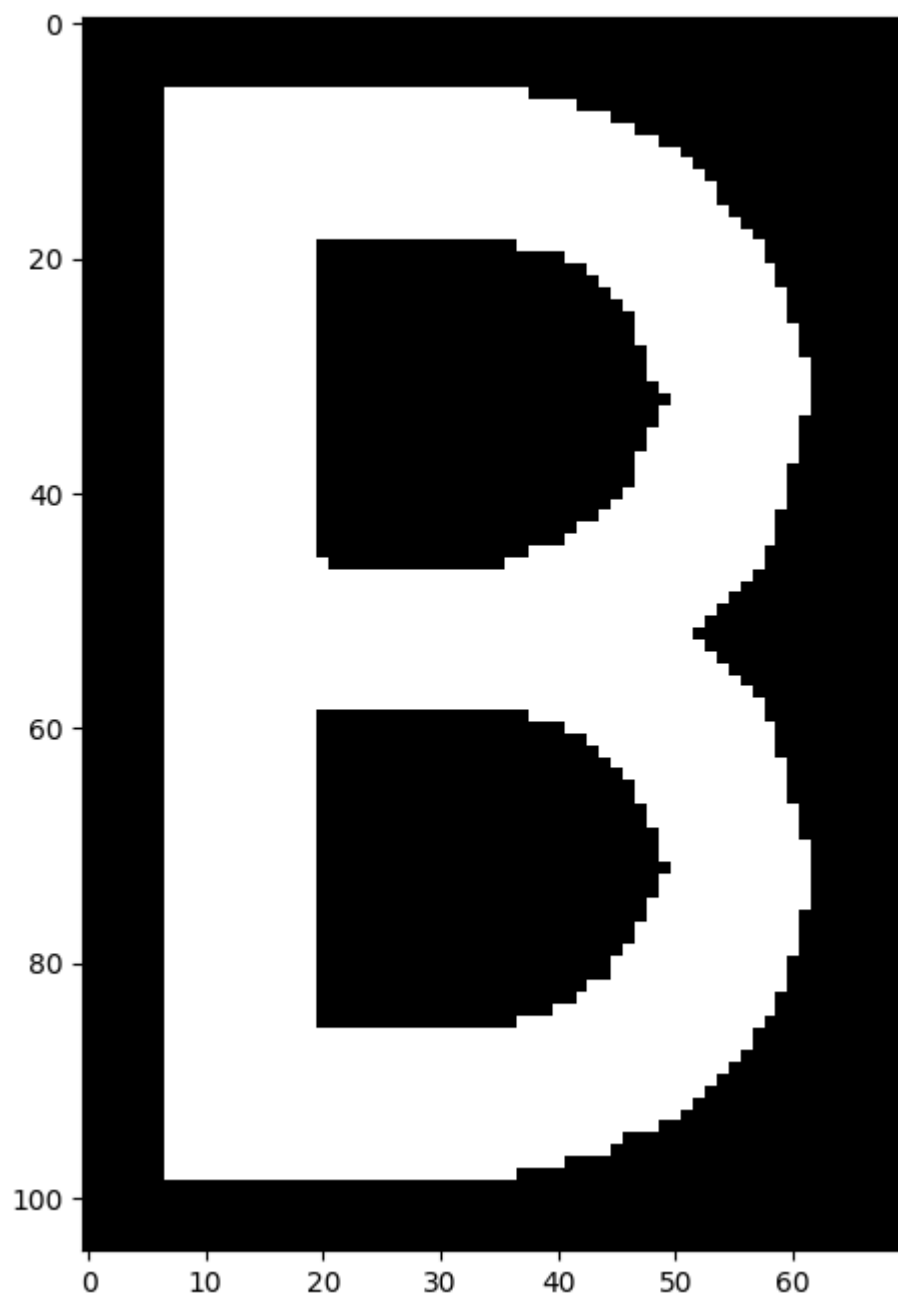
Perimeter: 255.68123936653137

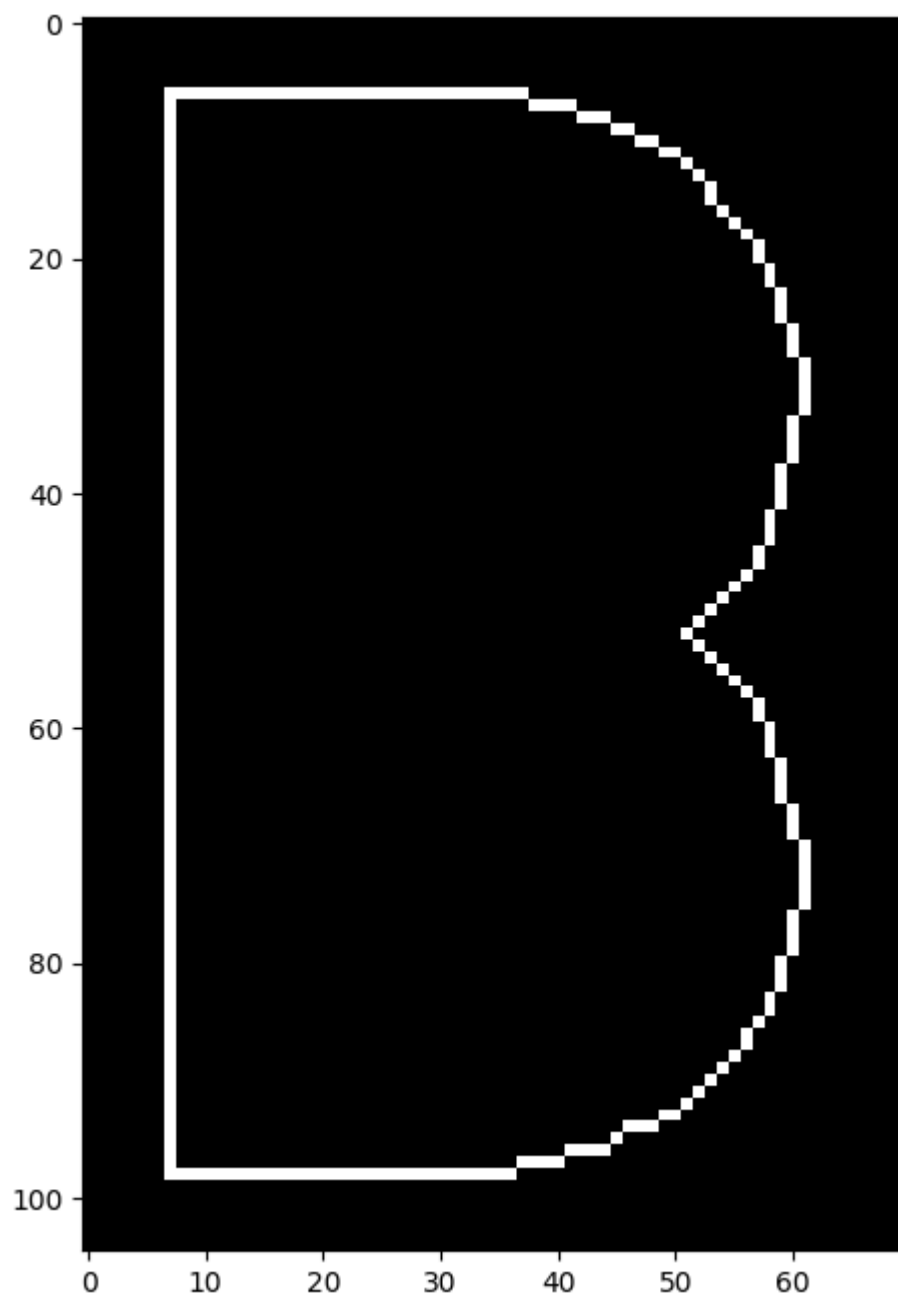




Area: 1386.0

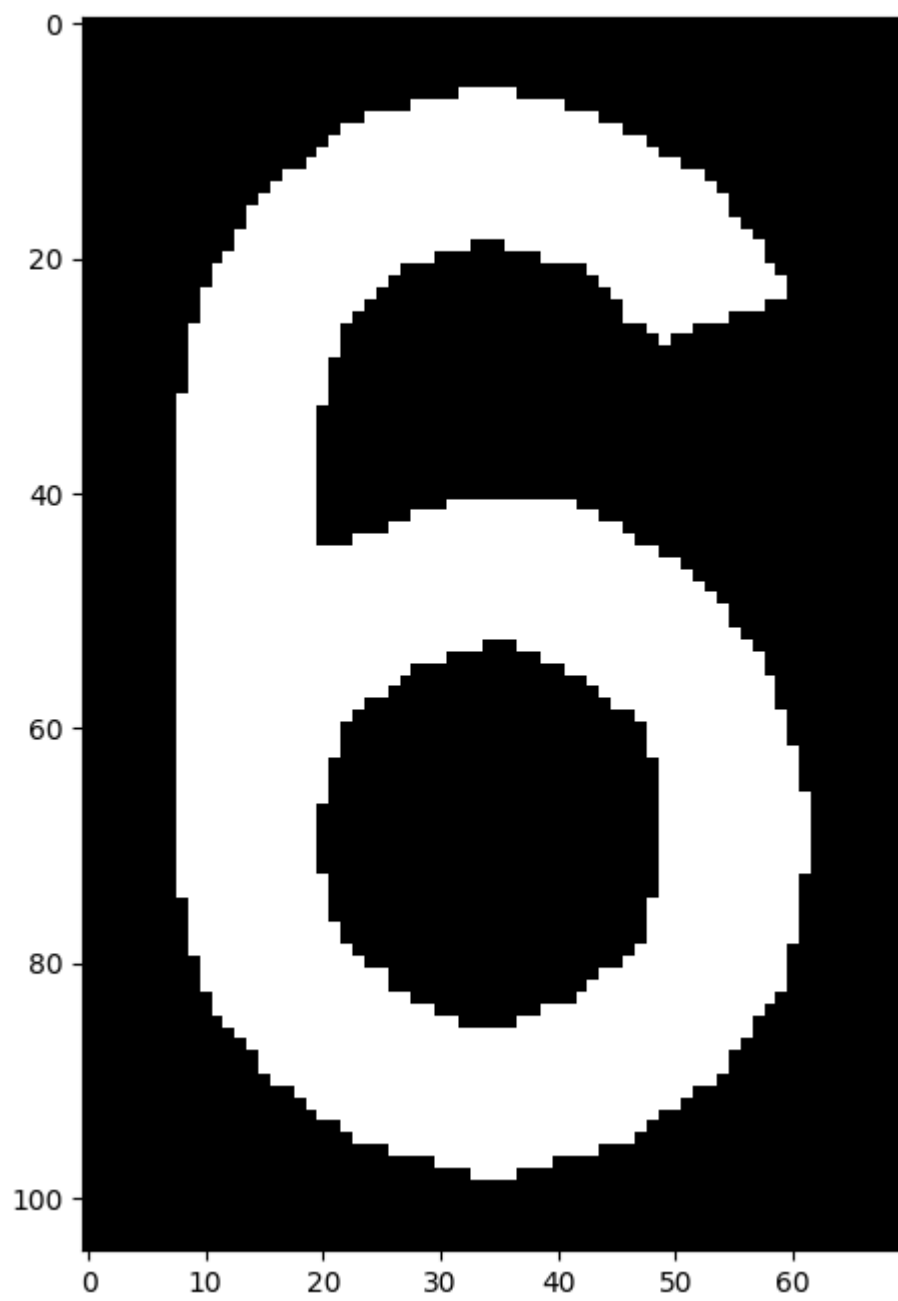
Perimeter: 276.3675310611725

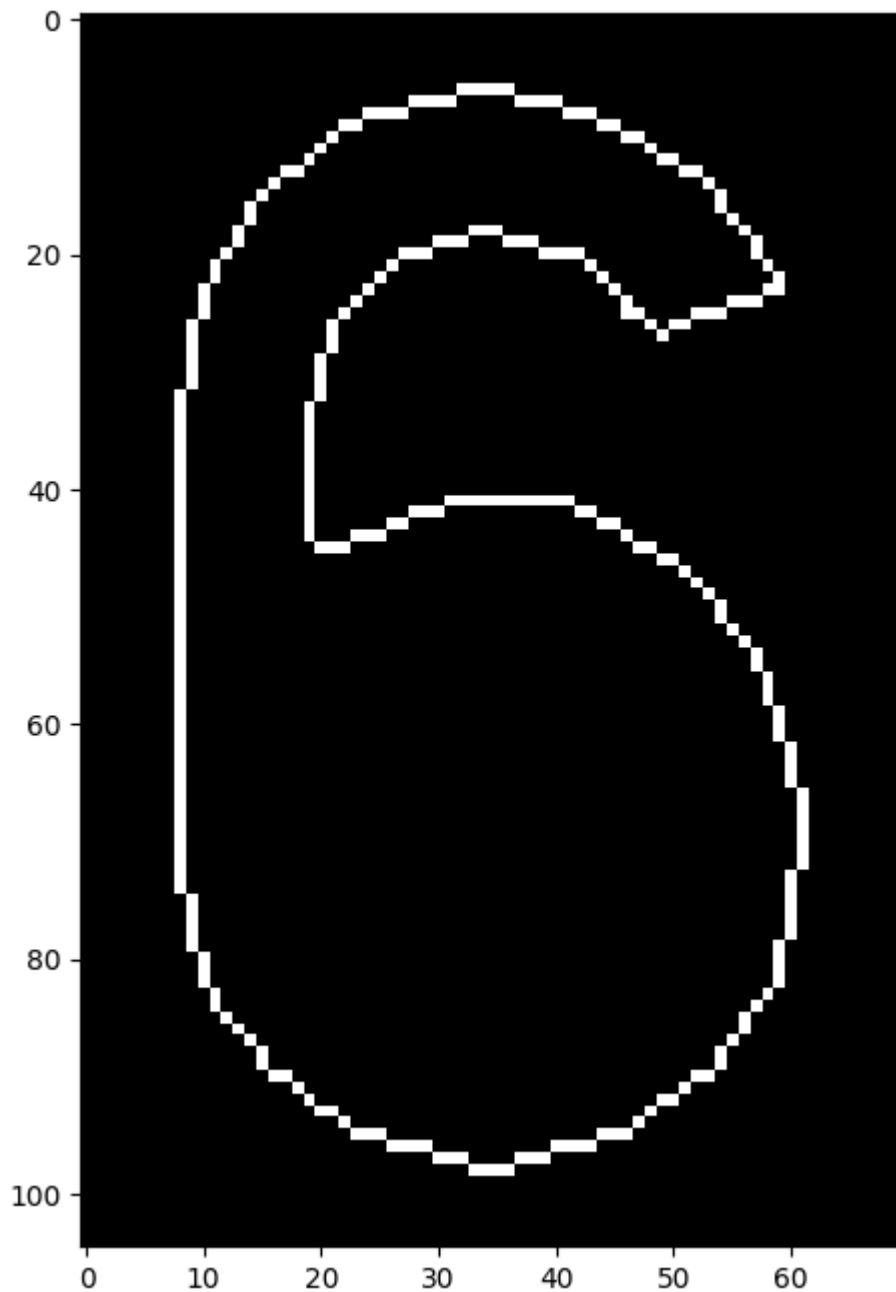




Area: 4498.0

Perimeter: 281.53910398483276





Area: 3217.5

Perimeter: 334.4924215078354

Compactness of 0: 0.06588

Compactness of J: 0.01815

Compactness of B: 0.05675

Compactness of 6: 0.02876

Expected output (using `CHAIN_APPROX_NONE`):

Compactness of 0: 0.06588

Compactness of J: 0.01815

Compactness of B: 0.05675

Compactness of 6: 0.02876

Thinking about it (1)

Excellent! Now, **answer the following questions:**

- Why `region_0.png` have the greatest compactness?

Since the shape that has the maximum compactness is a circle and number 0 is the most rounded shape out of all regions from which we obtained its contours, it is the one which has the greatest compactness.

- Could we differentiate all characters using only this feature as feature vector?

We can differentiate these 4, as number 0 is clearly on top, followed by the letter B (which has a pretty rounded contour as we only pay attention to the external one), followed by number 6 (same with B but top part has a hole) and lastly followed by letter J (the least rounded shape out of all). However, there are a lot of other characters which could have very similar compactness (such as the number 0 and the letter O), so we can not differentiate them all by only using this feature.

- Is compactness invariant to position, orientation or scale?

Yes, it is. Thanks to the perimeter being squared, compactness is indeed invariant to position, orientation and scale, as it results in a constant.

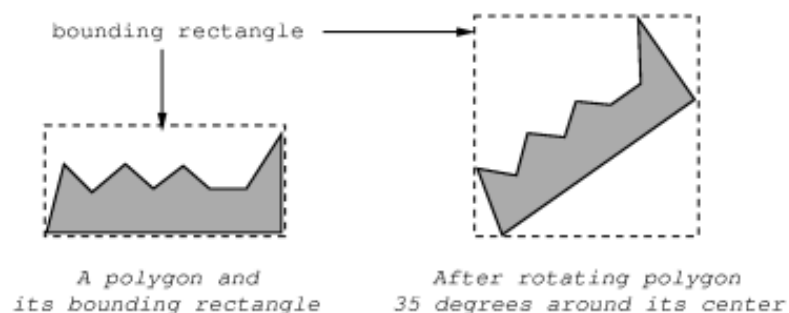
6.1.2 Extent

Another shape descriptor is **extent** of a shape:

$$\text{extent} = \frac{\text{area}}{\text{bounding rectangle area}}$$

\[5pt]

This feature associates the area of the region with the area its bounding rectangle. A **bounding rectangle** can be defined as the minimum rectangle that contains all the pixels of a region whose bottom edge is horizontal and its left edge is vertical.



The shape with the highest extent value is the rectangle, with $extent = 1$, while the lowest one is an empty region so $extent = 0$.

ASSIGNMENT 2: Time to compute the extent

Complete the function `extent()`, which receives the `region` to be described as input and returns its `extent`.

Tip: compute the bounding rectangle using `cv2.boundingRect()`, which also takes the contours as input.

```
In [5]: def extent(region):
        """ Compute the extent of a region.

        Args:
            region: Binary image

        Returns:
            extent: Extent of region (between 0 and 1)
        """

        # Get external contour
        contours,_ = cv2.findContours(region,cv2.RETR_CCOMP,cv2.CHAIN_APPROX_SIMPLE)
        cnt = contours[0]

        # Calcule area
        area = cv2.contourArea(cnt)

        # Get bounding rectangle
        _,_,w,h = cv2.boundingRect(cnt)

        # Calcule bounding rectangle area
        rect_area = w*h

        # Calcule extent
        extent = float(area)/rect_area

        return extent
```

You can use next code to **test if the obtained results are correct**:

```
In [6]: # Read the images
zero = cv2.imread(images_path + 'region_0.png',0)
J = cv2.imread(images_path + 'region_J.png',0)
B = cv2.imread(images_path + 'region_B.png',0)
six = cv2.imread(images_path + 'region_6.png',0)

# And show their extent!
print("Extent of 0: ", round(extent(zero),5), "\n",
      "Extent of J: ", round(extent(J),5), "\n",
      "Extent of B: ", round(extent(B),5), "\n",
      "Extent of 6: ", round(extent(six),5))
```

```
Extent of 0:  0.84203
Extent of J:  0.2866
Extent of B:  0.87937
Extent of 6:  0.64068
```

Expected output (using `CHAIN_APPROX_NONE`):

```
Extent of 0:  0.84203
Extent of J:  0.2866
Extent of B:  0.87937
Extent of 6:  0.64068
```

Thinking about it (2)

Now, **answer the following questions**:

- Why `region_B.png` have the greatest extent?

This is because it is the shape covering more area of the bounding rectangle, that is, the one of which shape is closest to being a rectangle.

- Is extent invariant to position, orientation or scale? If not, how could we turn it into a invariant feature?

It is invariant to position and scale, but definitely not to rotation, as the bounding rectangle changes with it. We could maybe align the longest edge of the region with one of the two axes of the bounding rectangle (as it has 90 degree rotation invariance).

6.1.3 Building a feature vector

Now that we can compute two different features, compactness (x_1) and extent (x_2), we can build a feature vector (\mathbf{x}) for characterizing each region by concatenating both features, that is, $\mathbf{x} = [x_1, x_2]$.

Before sending to UMA our solution for region description, let's see if these features are discriminative enough to differentiate between the considered characters.

ASSIGNMENT 3: Plotting feature vectors

You task is to plot the feature vectors, computed by the functions `compactness()` and `extent()`, in a 2D-space called the **feature space!** In such a space, the **x-axis represents the compactness** of a region and the **y-axis its extent**.

In this way, if the descriptions of the considered characters in this space don't appear close to each other, that means that they can be differentiated by relying on those features. **The problem appears if two or more characters have similar features** (their respective points are near). This tell us that **those features are just not enough** for automatically detect the plate characters.

Tip: [intro to pyplot](#).

```
In [7]: # Assignment 3
matplotlib.rcParams['figure.figsize'] = (6.0, 6.0)

# Read the images
zero = cv2.imread(images_path + 'region_0.png',0)
J = cv2.imread(images_path + 'region_J.png',0)
B = cv2.imread(images_path + 'region_B.png',0)
six = cv2.imread(images_path + 'region_6.png',0)

# Build the feature vectors
x_zero = np.array([compactness(zero), extent(zero)])
x_J = np.array([compactness(J), extent(J)])
x_B = np.array([compactness(B), extent(B)])
x_six = np.array([compactness(six), extent(six)])

# Define the scatter plot
```

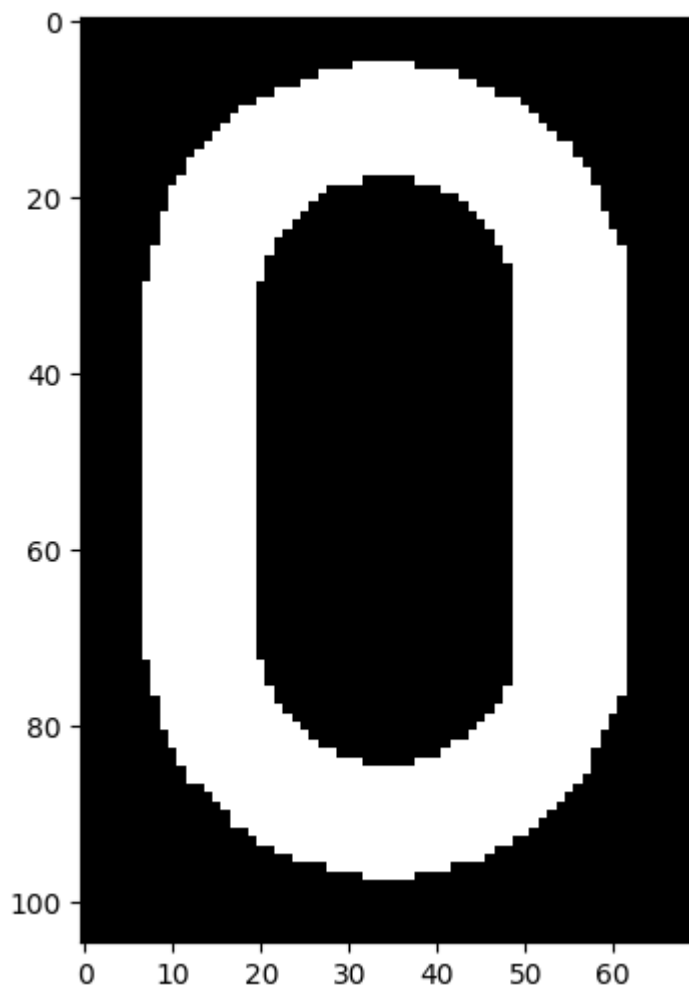


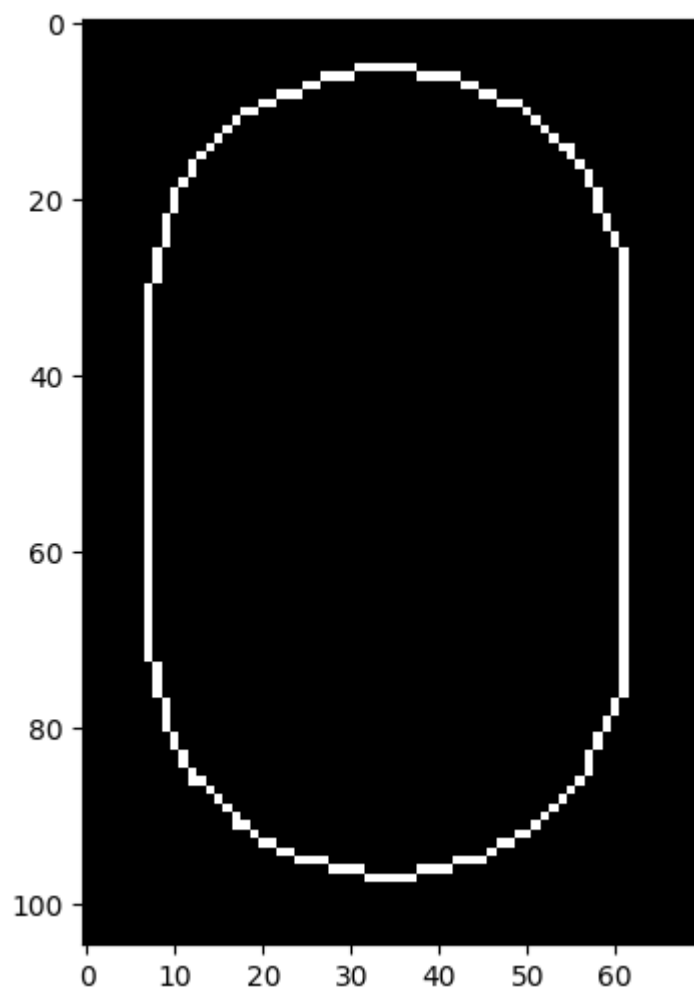
```

fig, ax = plt.subplots()
plt.axis([0, 1/(4*np.pi), 0, 1])
plt.xlabel("Compactness")
plt.ylabel("Extent")

# Plot the points
plt.plot(x_zero[0], x_zero[1], 'go')
plt.text(x_zero[0]+0.005, x_zero[1]+0.05, '0', bbox={'facecolor': 'green', 'alp
plt.plot(x_J[0], x_J[1], 'ro')
plt.text(x_J[0]+0.005, x_J[1]+0.05, 'J', bbox={'facecolor': 'red', 'alpha': 0.5
plt.plot(x_B[0], x_B[1], 'mo')
plt.text(x_B[0]+0.005, x_B[1]+0.05, 'B', bbox={'facecolor': 'magenta', 'alpha':
plt.plot(x_six[0], x_six[1], 'bo')
plt.text(x_six[0]+0.005, x_six[1]+0.05, '6', bbox={'facecolor': 'blue', 'alpha'

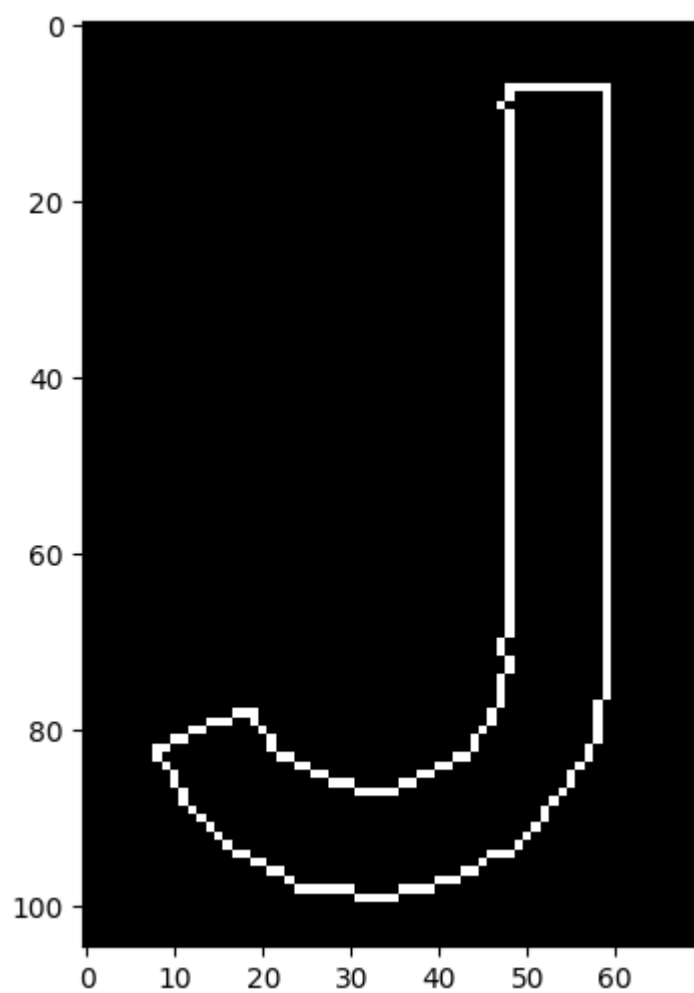
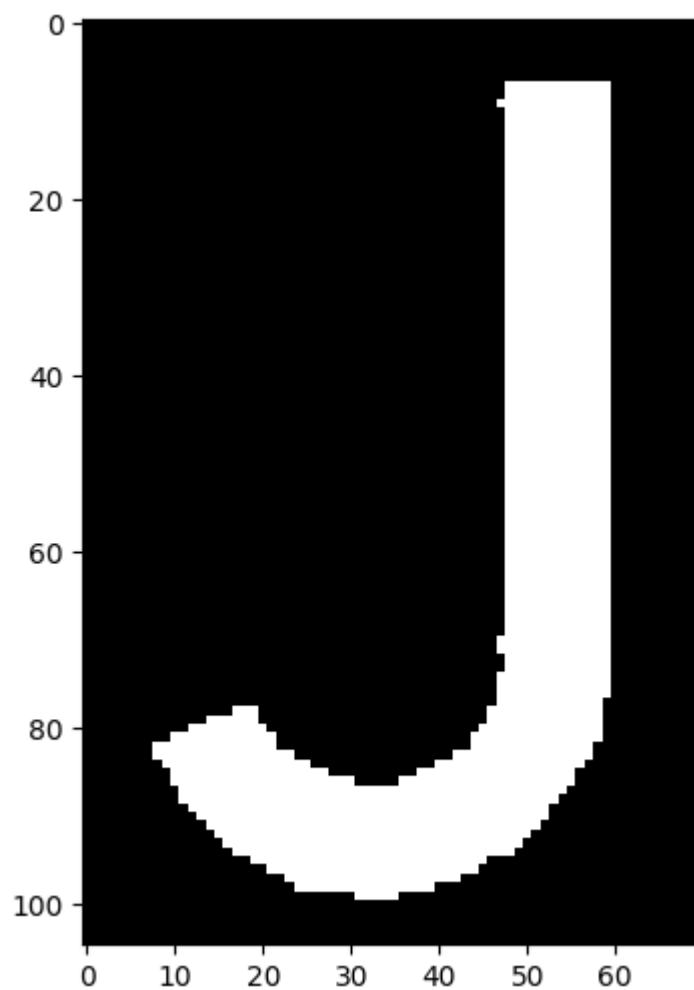
```





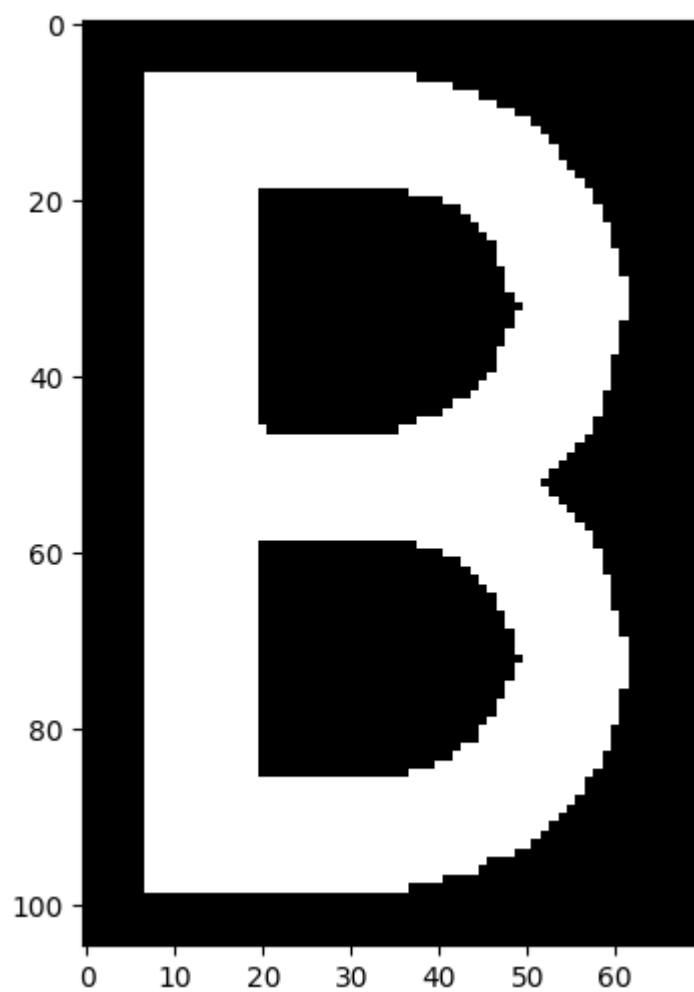
Area: 4307.0

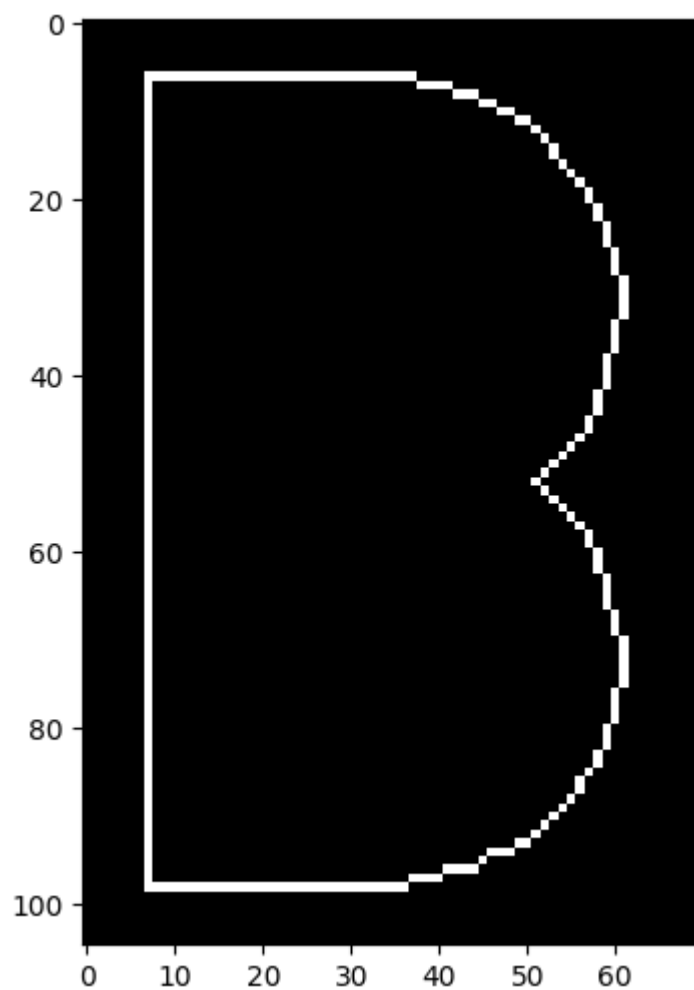
Perimeter: 255.68123936653137



Area: 1386.0

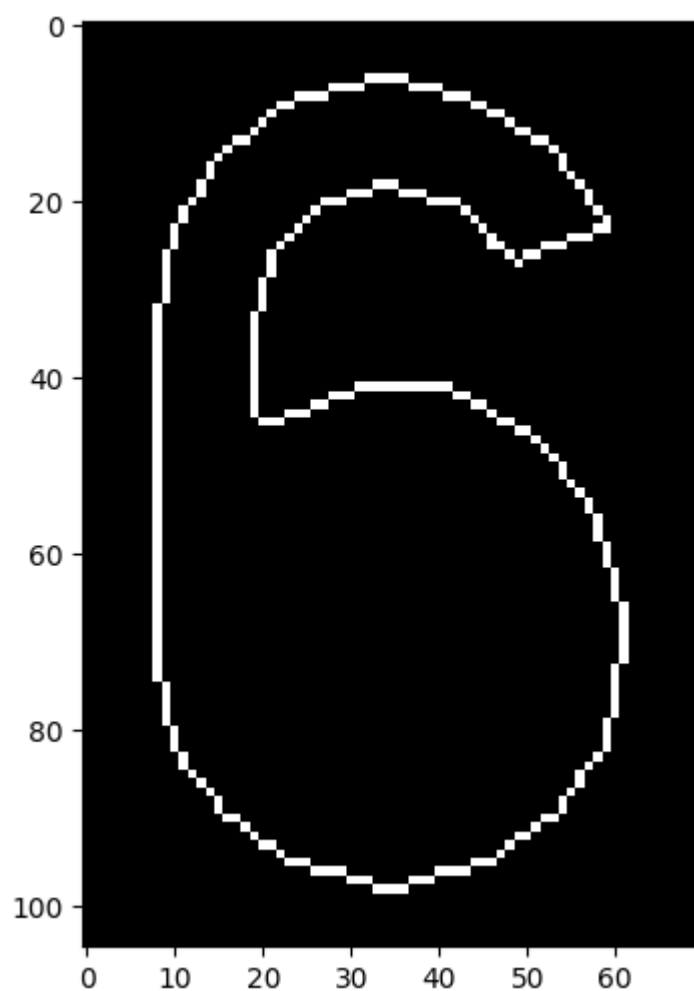
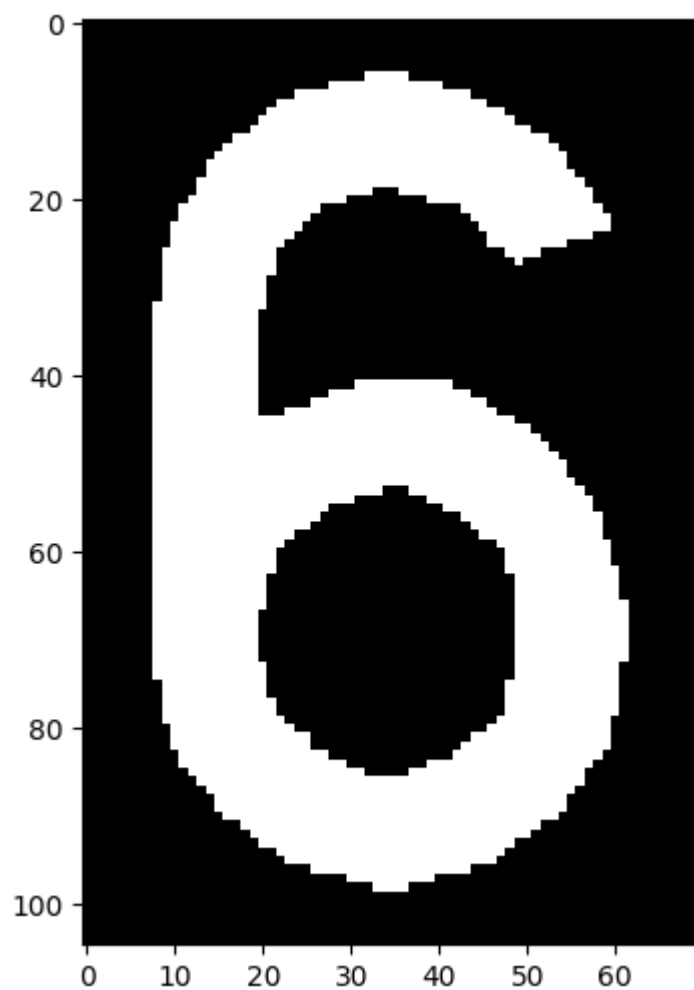
Perimeter: 276.3675310611725





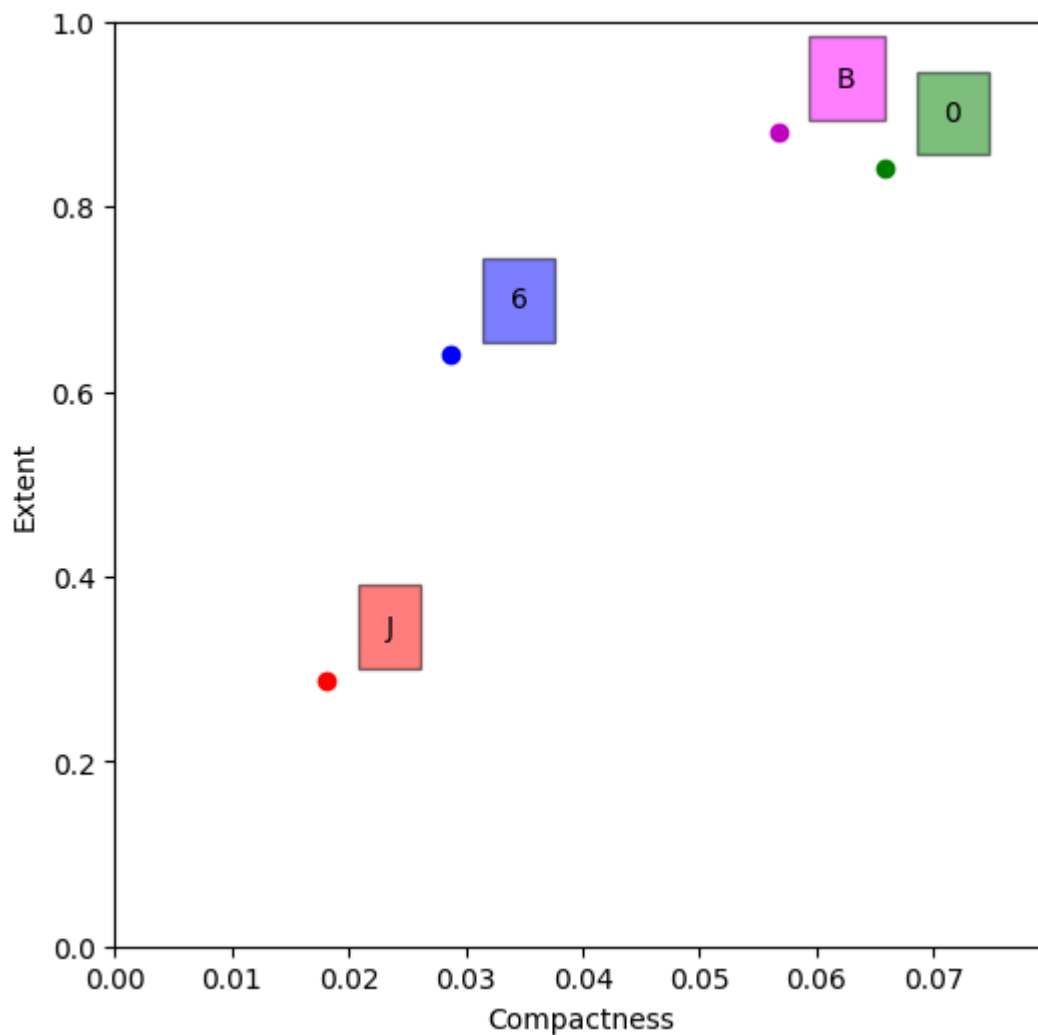
Area: 4498.0

Perimeter: 281.53910398483276



Area: 3217.5
Perimeter: 334.4924215078354

Out[7]: Text(0.033757159783557804, 0.6906810035842295, '6')



Thinking about it (3)

What do you think?

- Are they discriminative enough?

No, they are not. Even though some points can be distinguished from one another (e.g., letter J and number 6), others are very close and can lead to confusion (e.g., letter B and number 0).

- If your answer is no, how could we handle this problem?

We could maybe try other feature vector (combining other features or adding more to the one used).

OPTIONAL

Surf the internet looking for **more shape features**, and try to find a pair of them working better than compactness and extent.

END OF OPTIONAL PART

OPTIONAL

Take an image of a car plate, apply the techniques already studied in the course to improve its quality, and binarize it. Then, extract some shape features and check where the numbers/letters are projected in the feature space.

END OF OPTIONAL PART

Conclusion

Great work! You have learned about:

- what is the aim of region descriptors,
- the ideas behind two simple shape descriptors: compactness and extent, and
- to build a vector of features and analyze its discriminative power.

Unfortunately, it seems that those two features are not enough to differentiate the plate characters, so let's try more complex descriptors in the next notebook!

Extra work

Surf the internet looking for **more shape features**, and try to find a pair of them working better than compactness and extent.