

# 1. Theoretical Tasks

## 1.1 Image Convolution calculation

### Theoretical Background

Read the following two blog posts:

***What are convolutions?:***

<https://vaulttech.github.io/2017/08/12/what-are-convolutions/>

***Convolutions and Neural Networks:***

<https://vaulttech.github.io/2017/08/28/convolutions-and-neural-networks/>

### Task

Now consider the following image  $I$ , represented as a matrix:

$$I = \begin{bmatrix} 1 & 2 & 2 \\ -1 & -2 & -2 \\ -1 & -1 & -1 \end{bmatrix}$$

And the following kernel  $k$ , represented as a matrix:

$$k = \begin{bmatrix} 1 & 1 & 1 \\ 2 & 2 & 1 \\ 1 & -2 & 1 \end{bmatrix}$$

Calculate a *same* convolution  $I * k$  as described in **Convolutions and Neural Networks** above.

## 1.2 Max Pooling calculation

### Theoretical Background

Max Pooling divides the input image in several sections of a given size. This size is generally referred to as *filter size*. Then, for each section, we only return the biggest value present in that section. For example, in the image below, the sections are of size  $(2, 2)$ :

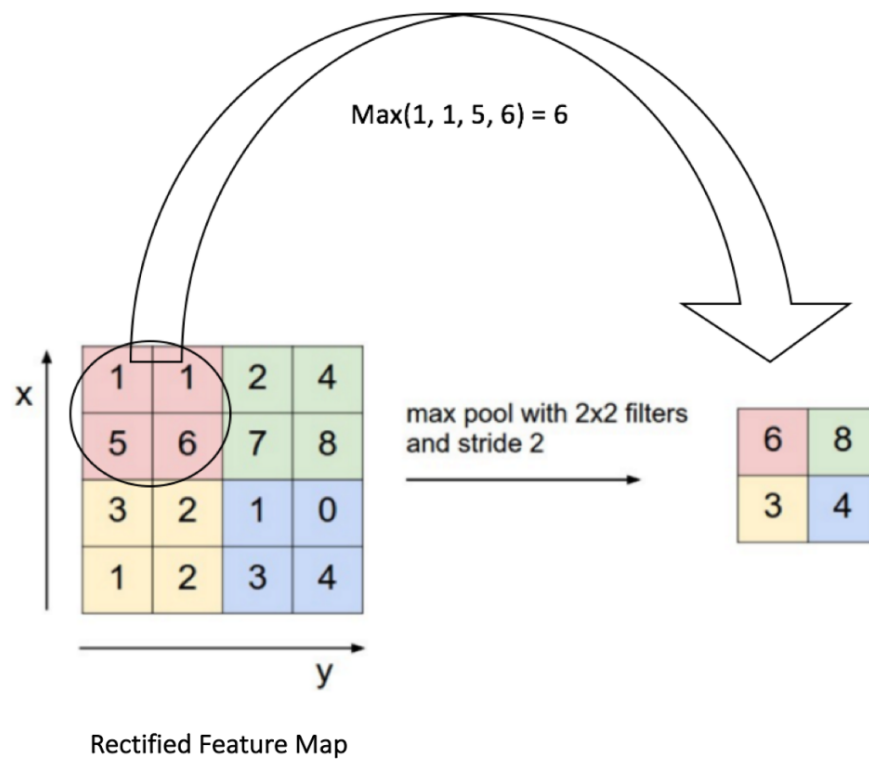


Figure 1: Max Pooling operation with a filter of size (2,2) (adapted from <http://linkis.com/ujjwalkarn.me/2016/0/pRidi>)

It is easy to notice that the output image will have a smaller size than the input. In this case, because the filter size is (2,2), the final size of the image half of the original image. If it were (3,3), then the final size would be one third of the original image.

When the filter size in both dimensions is the same, it is common to refer to it using just one number. For example, `filter_size = 3` would mean that the filter size is 3 both horizontally and vertically.

### Task

Given the image  $I$  below, represented as a matrix, apply Max Pooling with a filter size of 3. Use `stride = 3`:

$$I = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 6 & 2 & 3 & 1 & 0 \\ 0 & -1 & 2 & -2 & -1 & 0 \\ 0 & -1 & -1 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

### 1.3 A Neural Network example

The Convolution and the Max Pooling operation above can be combined to build a CNN. In general, the Convolutional layer is followed by a nonlinearity, and finally by Max Pooling layer. The process can be repeated several times. At the end, it is common to have a fully connected layer followed by a softmax. In the exercise below you have to calculate by hand each one of the steps.

- 1) First, calculate a *valid* convolution between the image  $I$  and the kernel  $k$ . Use `stride = 1`:

$$I = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 1 & 2 & 2 & 1 & 0 \\ 0 & -1 & -2 & -2 & -1 & 0 \\ 0 & -1 & -1 & -1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k = \begin{bmatrix} 1 & 1 & 1 \\ 2 & 2 & 1 \\ 1 & -2 & 1 \end{bmatrix}$$

- 2) Then calculate the output of the Rectified Linear Unit;
- 3) Then apply 2x2 Max Pooling to the resulting matrix (use `stride = 2`);

- 4) Now flatten the resulting image by putting all the rows of the image in one same line. For example, the image below:

$$I = \begin{bmatrix} 0 & 1 \\ 2 & 3 \end{bmatrix}$$

will become:

$$I_{flattened} = [0, 1, 2, 3]^T$$

- 5) Calculate the output of a Fully Connected layer. Use the following  $W$ :

$$W = \begin{bmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \end{bmatrix}$$

- 6) Finally, you will have 2 outputs. It is common to apply a softmax operation over these outputs. **Hint:** since in our case we have only two classes, think about what does that mean for the softmax operation.