# 深度學習
# Deep Learning

## Convolutional Neural Networks (CNN)

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**2025/10/08**

Course GitHub

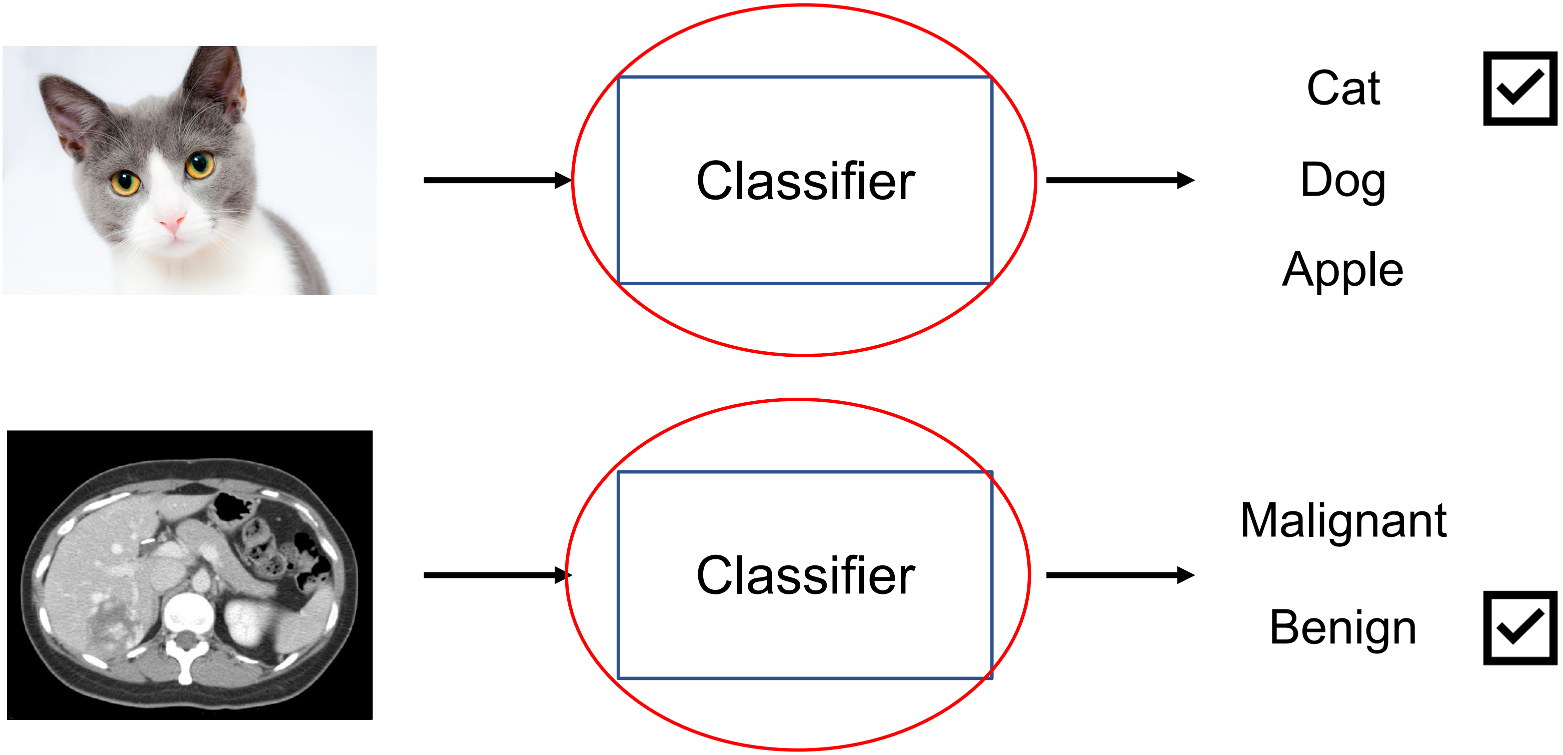
Slido # DL1008

# Outline

- Images [10 min]
- Convolutional Neural Networks [50 min]
- CV (Computer Vision) in PyTorch [40 min]
- HW2 [30 min]
- Quiz [20 min]

# 什麼是機器學習？(以電腦視覺為例)

Machine Learning function!



Classifier

Cat ☑

Dog

Apple

Classifier

Malignant

Benign ☑

# LeNet-5: Early Convolutional Neural Networks

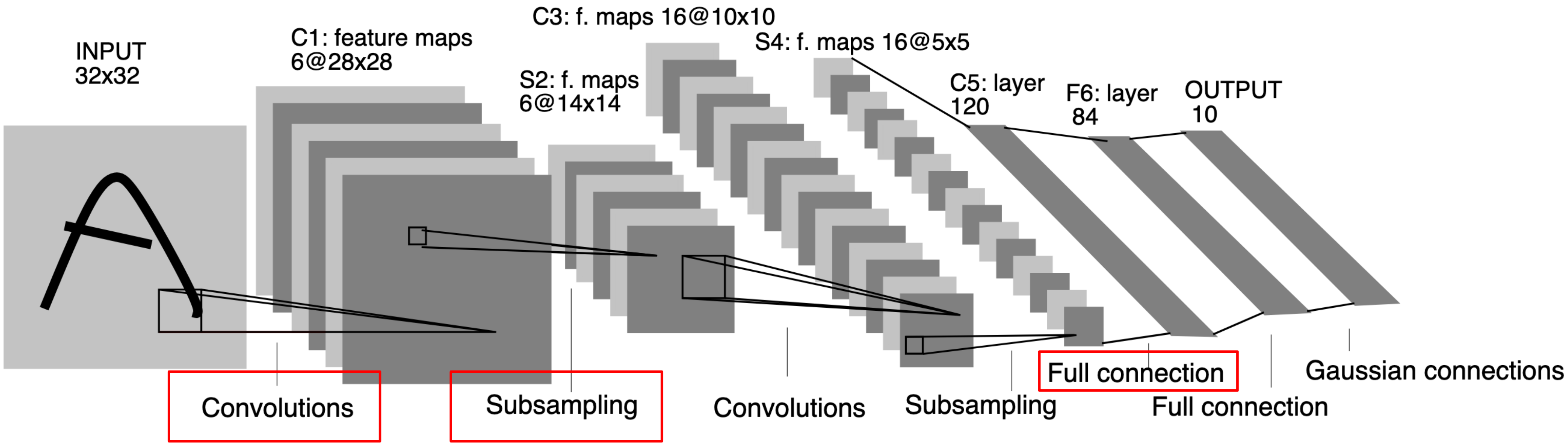
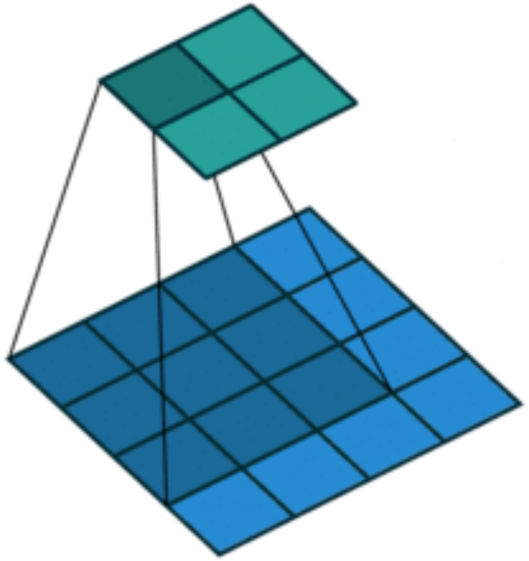


Fig. 2. Architecture of LeNet-5, a Convolutional Neural Network, here for digits recognition. Each plane is a feature map, i.e. a set of units whose weights are constrained to be identical.

LeCun, Y., Bottou, L., Bengio, Y., & Haffner, P. (1998). Gradient-based learning applied to document recognition. Proceedings of the IEEE, 86(11), 2278-2324.

# Examples of Convolutions

Padding = 0, stride = 1



Padding = 0, stride = 2

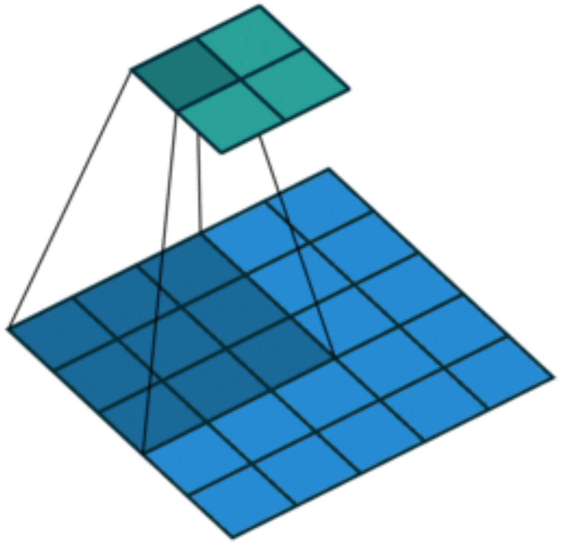
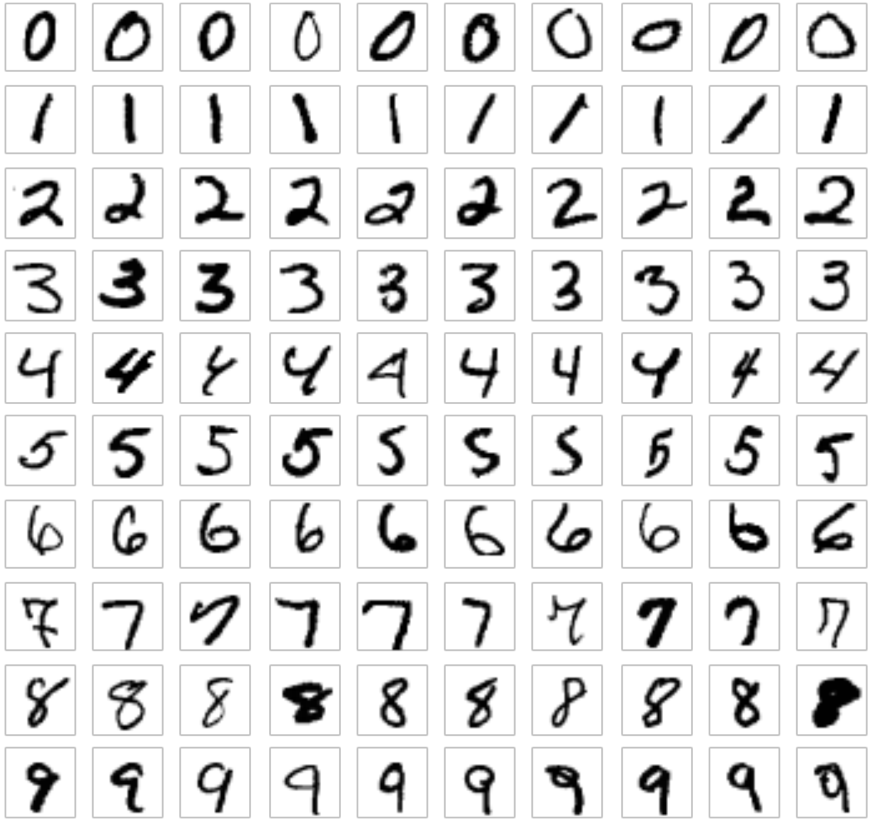


Figure source:
https://hannibunny.github.io/mlbook/neuralnetworks/convolutionDemos.html

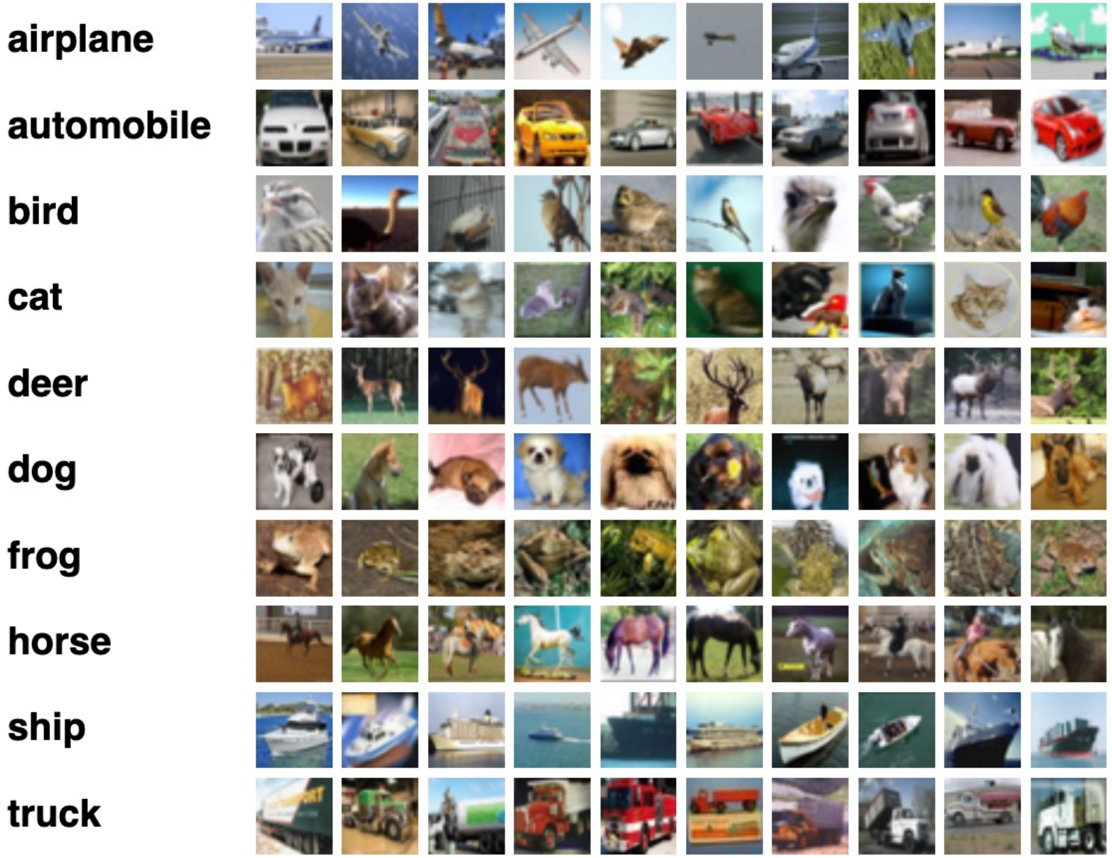
# Images

## MNIST



http://yann.lecun.com/exdb/mnist/

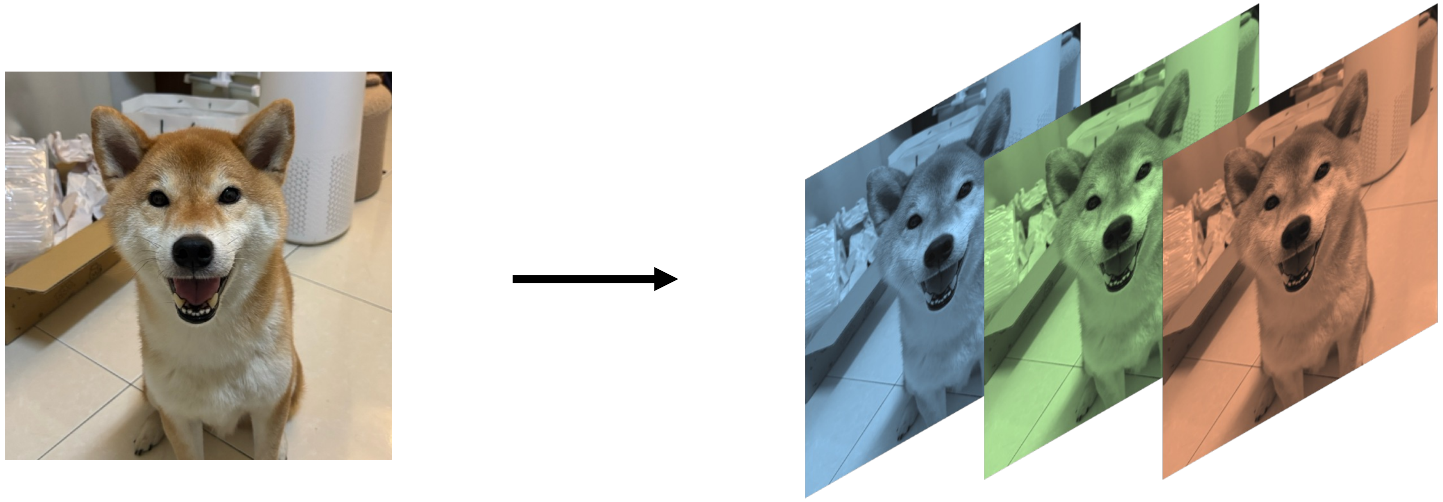
## CIFAR-10



https://www.cs.toronto.edu/~kriz/cifar.html

# RGB Images (彩色影像)

- RGB 代表紅色 (Red)、綠色 (Green) 及藍色 (Blue)



Example shape:
(3, 128, 128)

channels height width

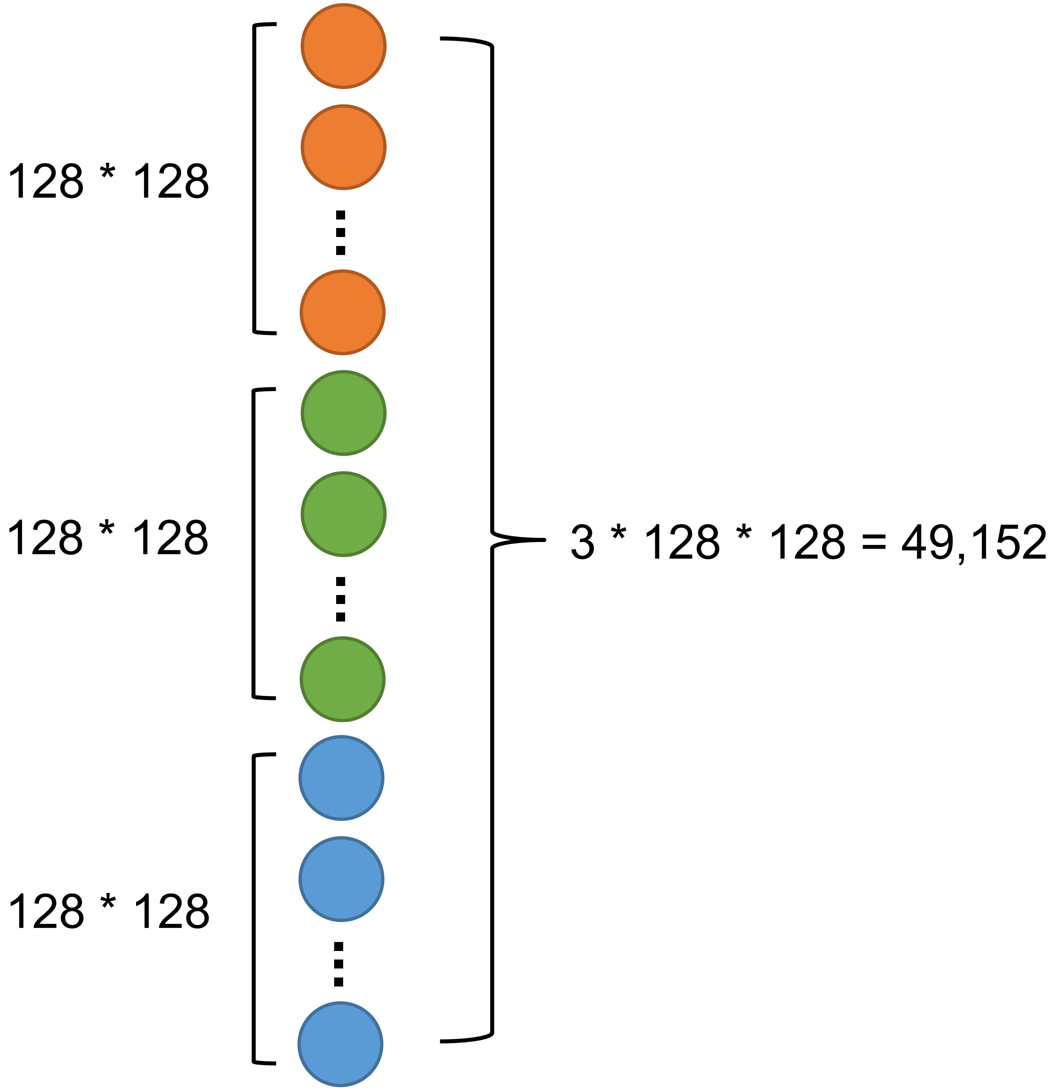
# Gray-scale Images (灰階影像)

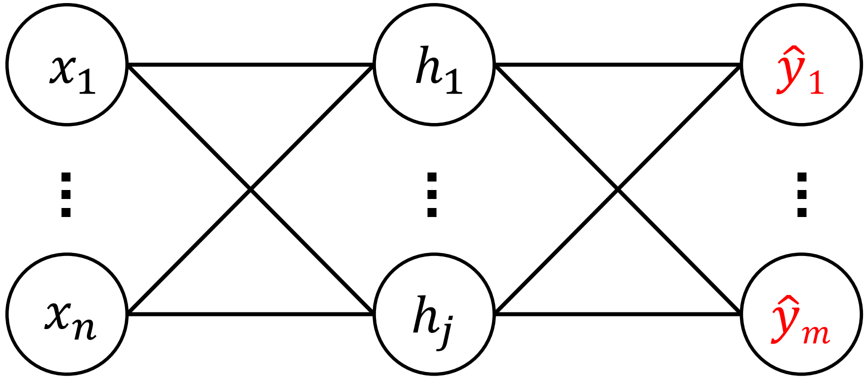
- 灰階影像只有一個 channel

Example shape:
(1, 128, 128)

channels height width

# Image inputs are too big for an MLP





n = 49,152

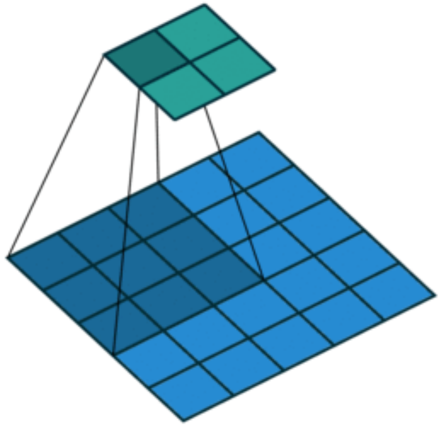
# Convolutional Neural Networks

CNN

# 卷積層有兩個重要的設定參數

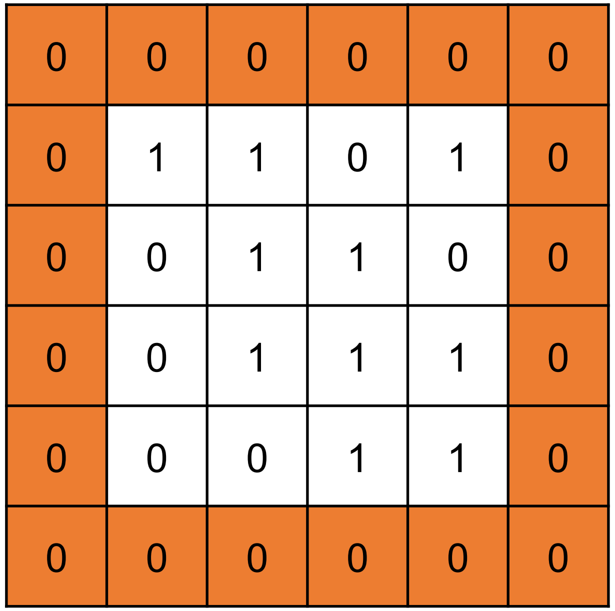
https://docs.pytorch.org/docs/stable/generated/torch.nn.Conv2d.html

- stride (int): 步長，代表卷積一次走幾個像素點
- padding (int): 影像的四個邊要不要補 0



Padding = 0, stride = 2

Figure source: https://hannibunny.github.io/mlbook/neuralnetworks/convolutionDemos.html



| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

(白色代表原始影像區域，橘紅色代表padding)

# Convolutions (stride = 1)

沒有 padding

Stride = 1

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

|   |   |   |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

|   |
|---|
| 1 |

# Convolutions (stride = 1)

沒有 padding

Stride = 1

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

|   |   |   |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

|   |   |
|---|---|
| 1 | 1 |

# Convolutions (stride = 1)

沒有 padding

Stride = 1

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

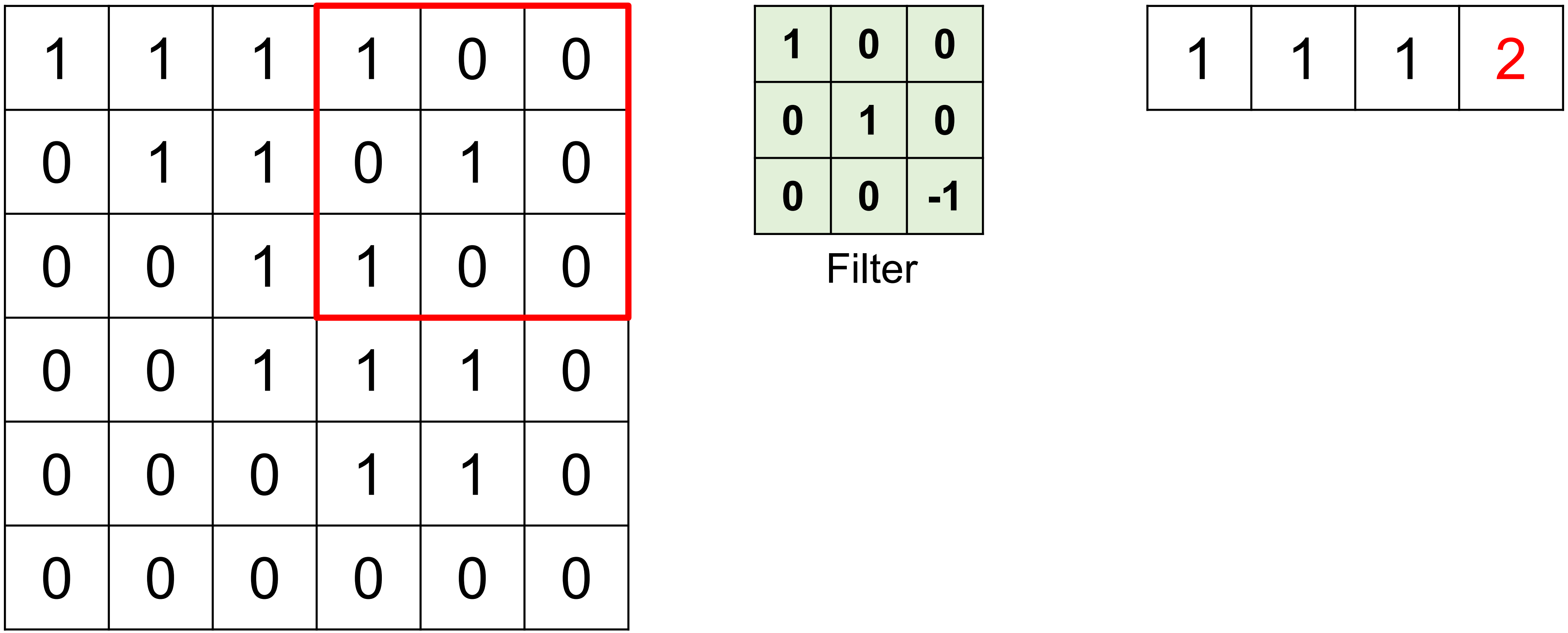
Filter

| | | |
|---|---|---|
| 1 | 1 | 1 |

# Convolutions (stride = 1)

Stride = 1

沒有 padding



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

|   |   |   |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

|   |   |   |   |
|---|---|---|---|
| 1 | 1 | 1 | 2 |

# Convolutions (stride = 1)

沒有 padding

Stride = 1

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

| | | | |
|---|---|---|---|
| 1 | 1 | 1 | 2 |
| -1 | | | |

# Convolutions (stride = 1)

沒有 padding

Stride = 1

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

| | | | |
|---|---|---|---|
| 1 | 1 | 1 | 2 |
| -1 | 1 | | |

# Convolutions (stride = 1)

沒有 padding

Stride = 1

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

| | | | |
|---|---|---|---|
| 1 | 1 | 1 | 2 |
| -1 | 1 | 1 | 0 |
| 0 | 0 | 1 | 2 |
| 0 | 0 | 1 | 2 |

feature map

# Convolutions (stride = 1)

沒有 padding

Stride = 2

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

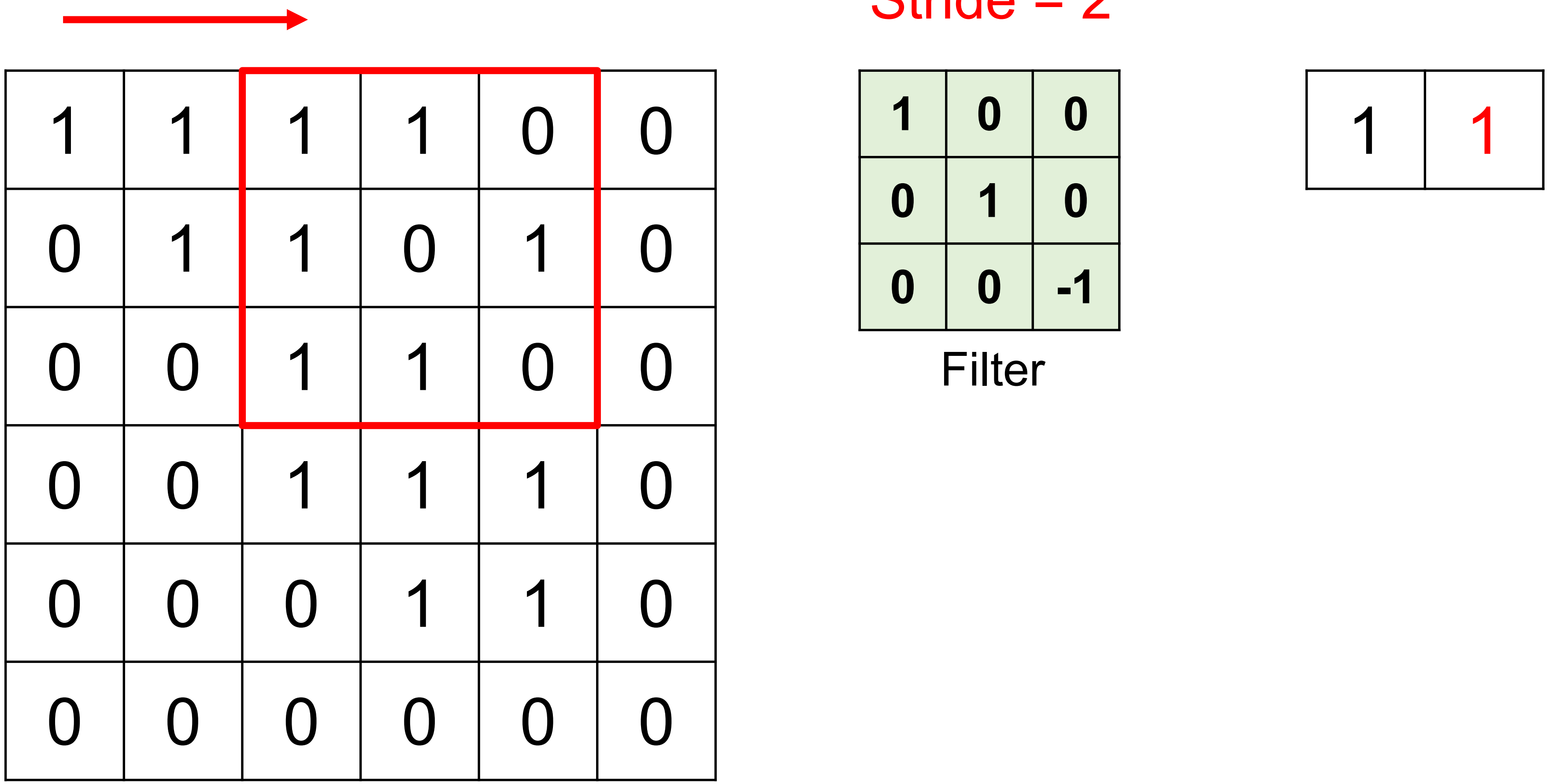
Filter

| |
|---|
| 1 |

# Convolutions (stride = 2)

沒有 padding

Stride = 2



|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

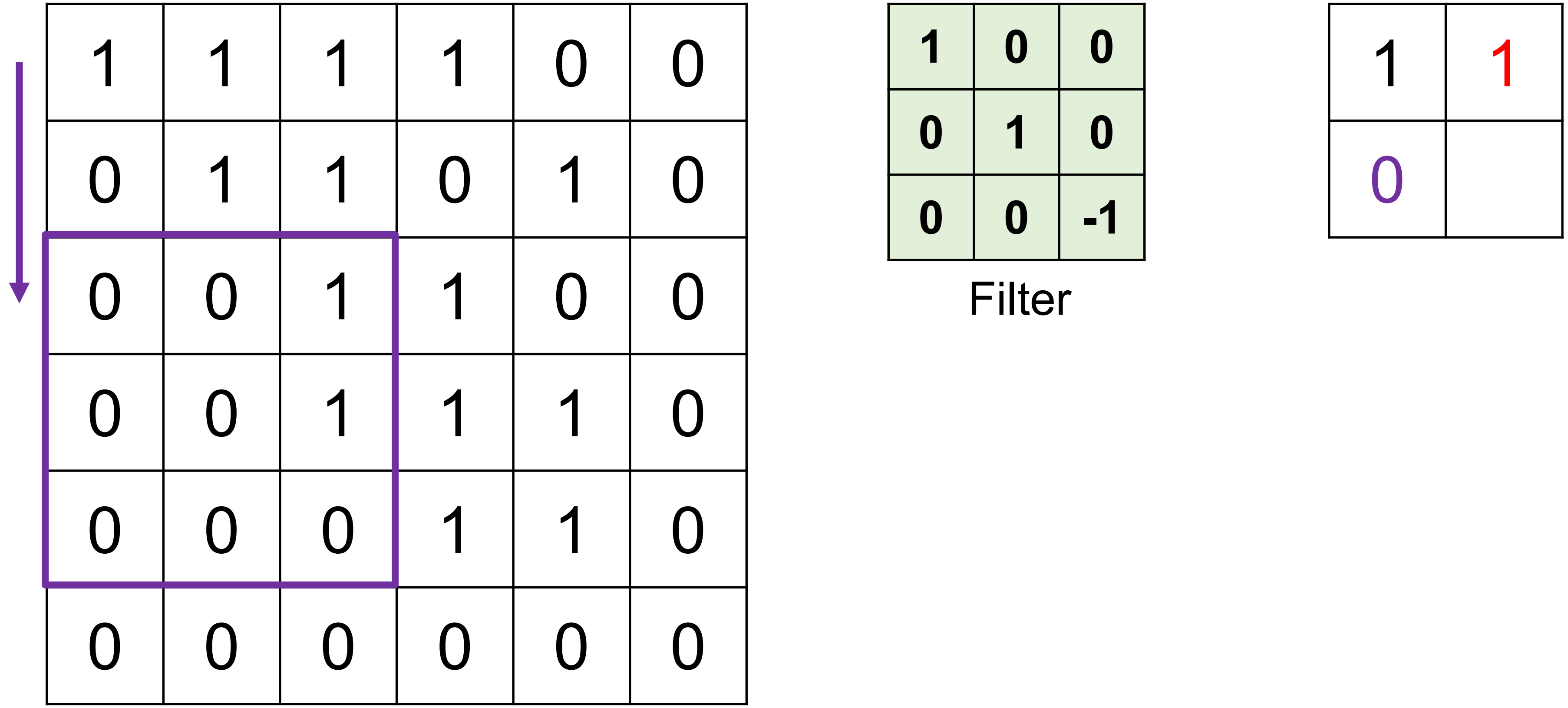
|   |   |   |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

Filter

|   |   |
|---|---|
| 1 | 1 |

# Convolutions (stride = 2)

Stride = 2



| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

| | | |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

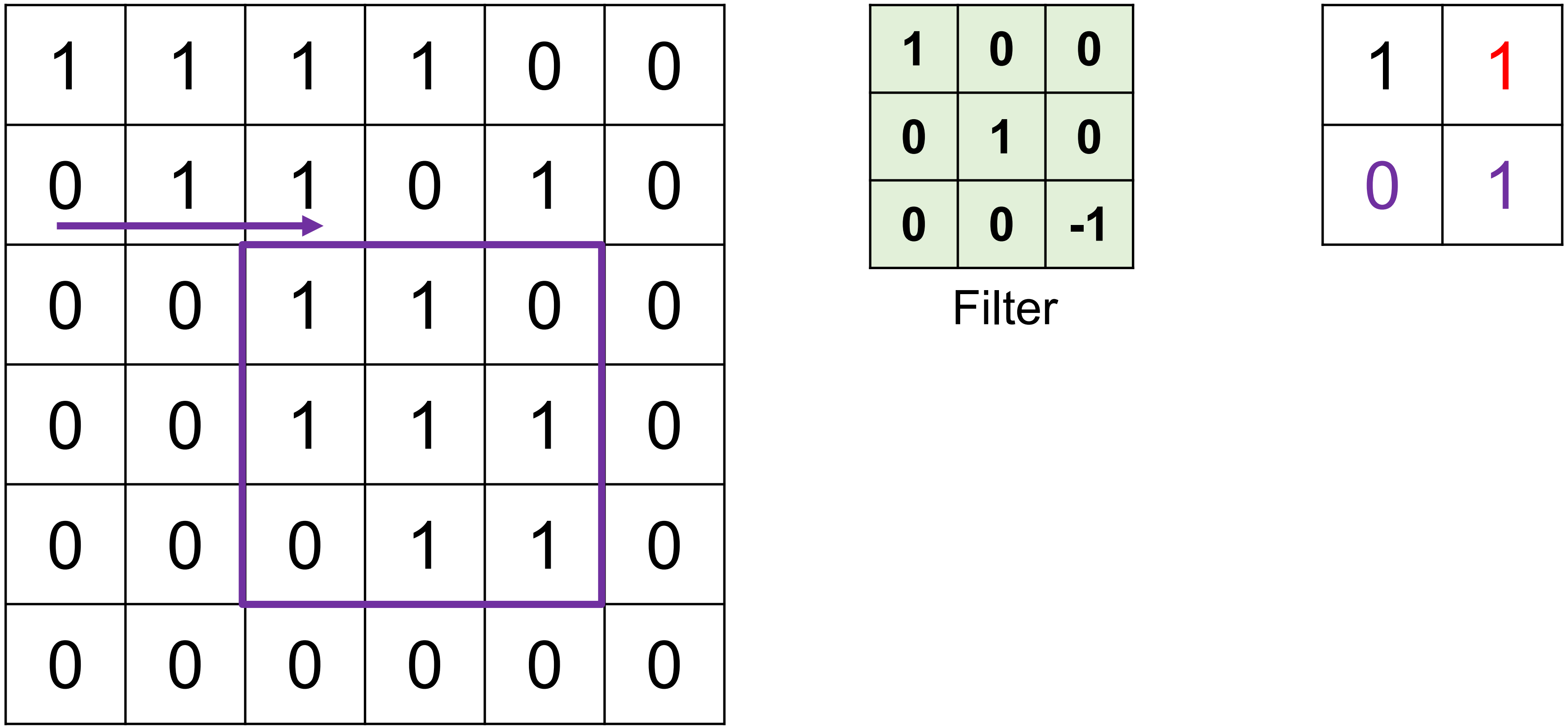
Filter

| | |
|---|---|
| 1 | 1 |
| 0 | |

# Convolutions (stride = 2)

沒有 padding

Stride = 2



|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

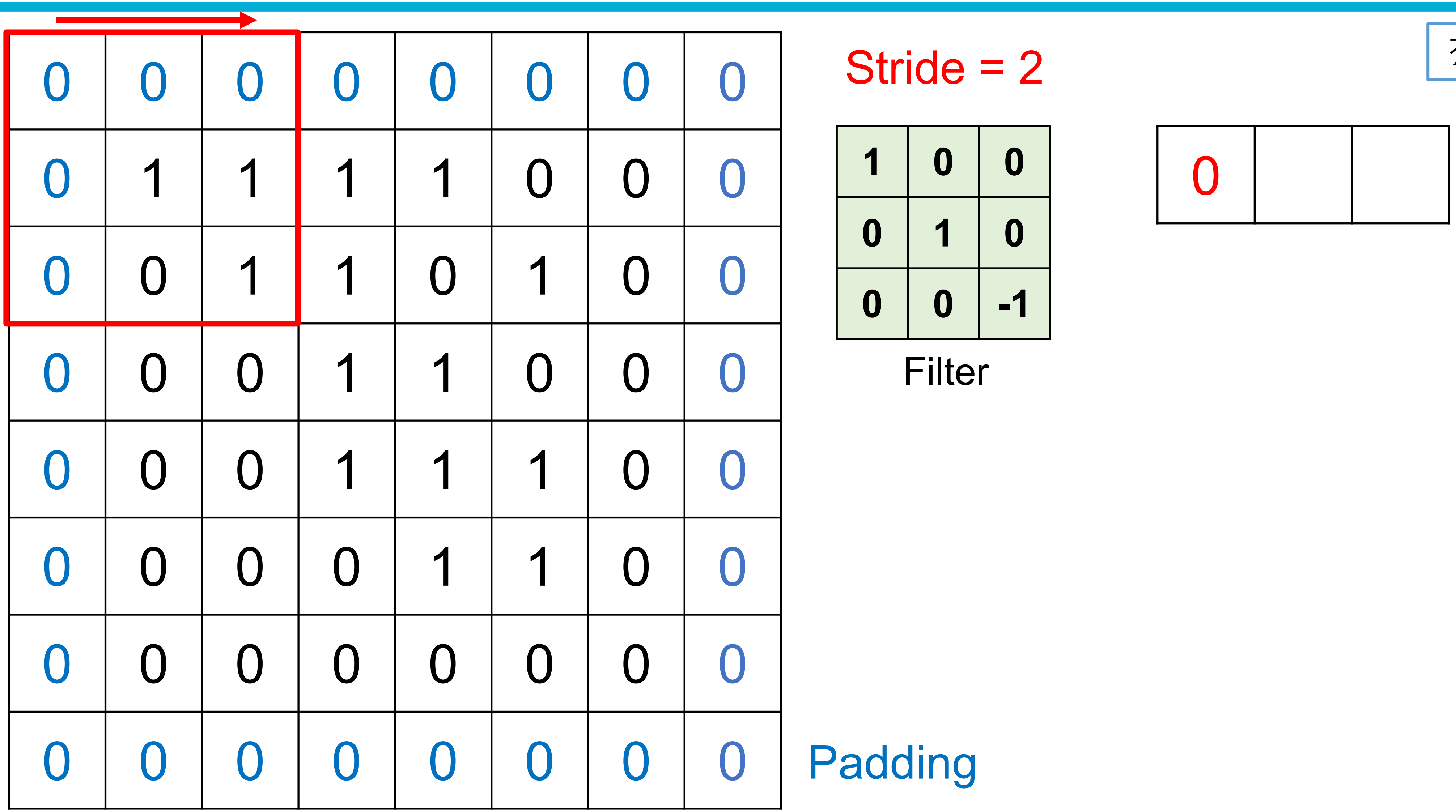
|  |  |  |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

Filter

|  |  |
|---|---|
| 1 | 1 |
| 0 | 1 |

# Convolutions (stride = 2, padding = 1)

有 padding



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Padding

Stride = 2

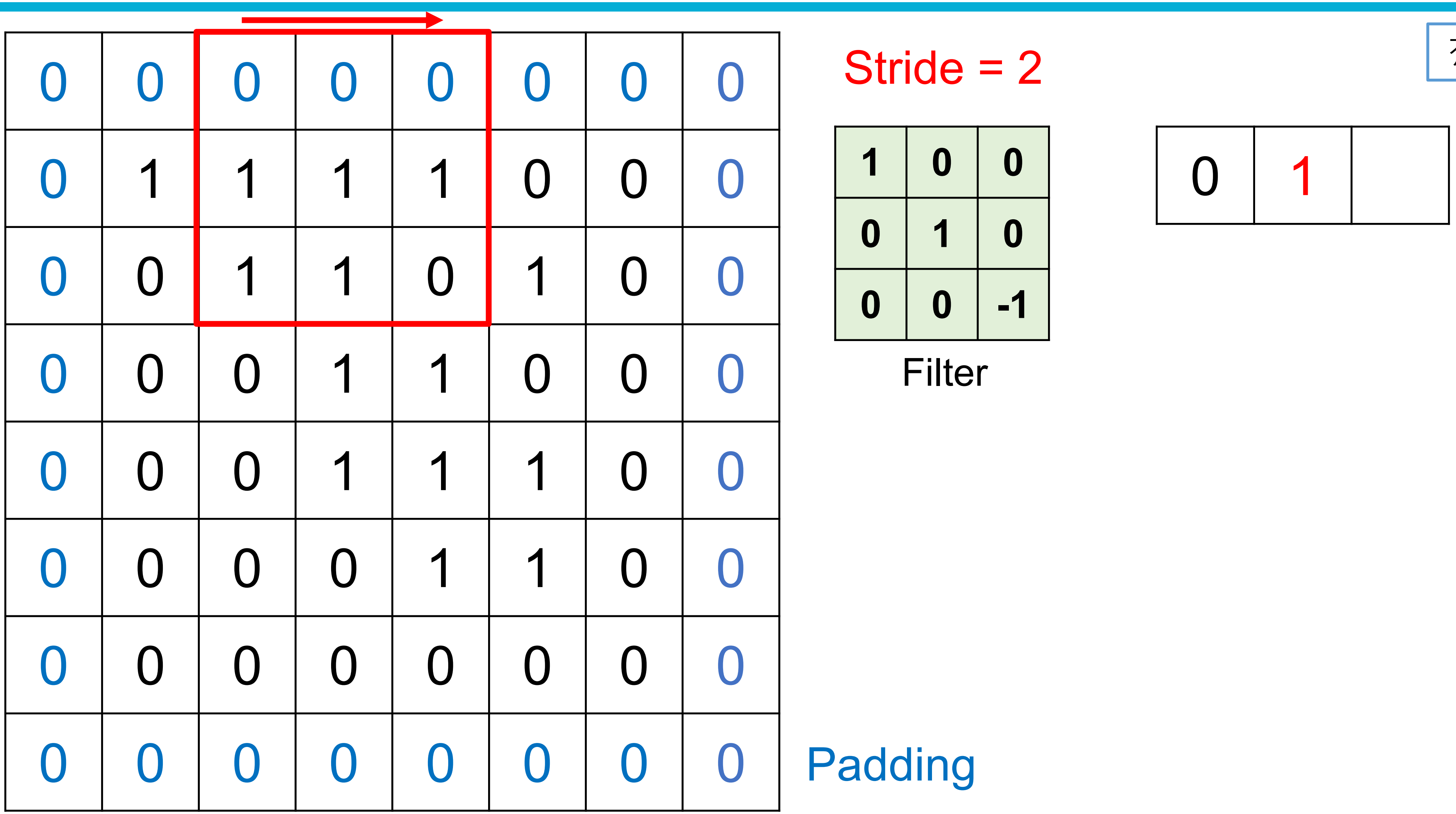
| | | |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

Filter

| | | |
|---|---|---|
| 0 | | |

# Convolutions (stride = 2, padding = 1)

有 padding



Stride = 2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

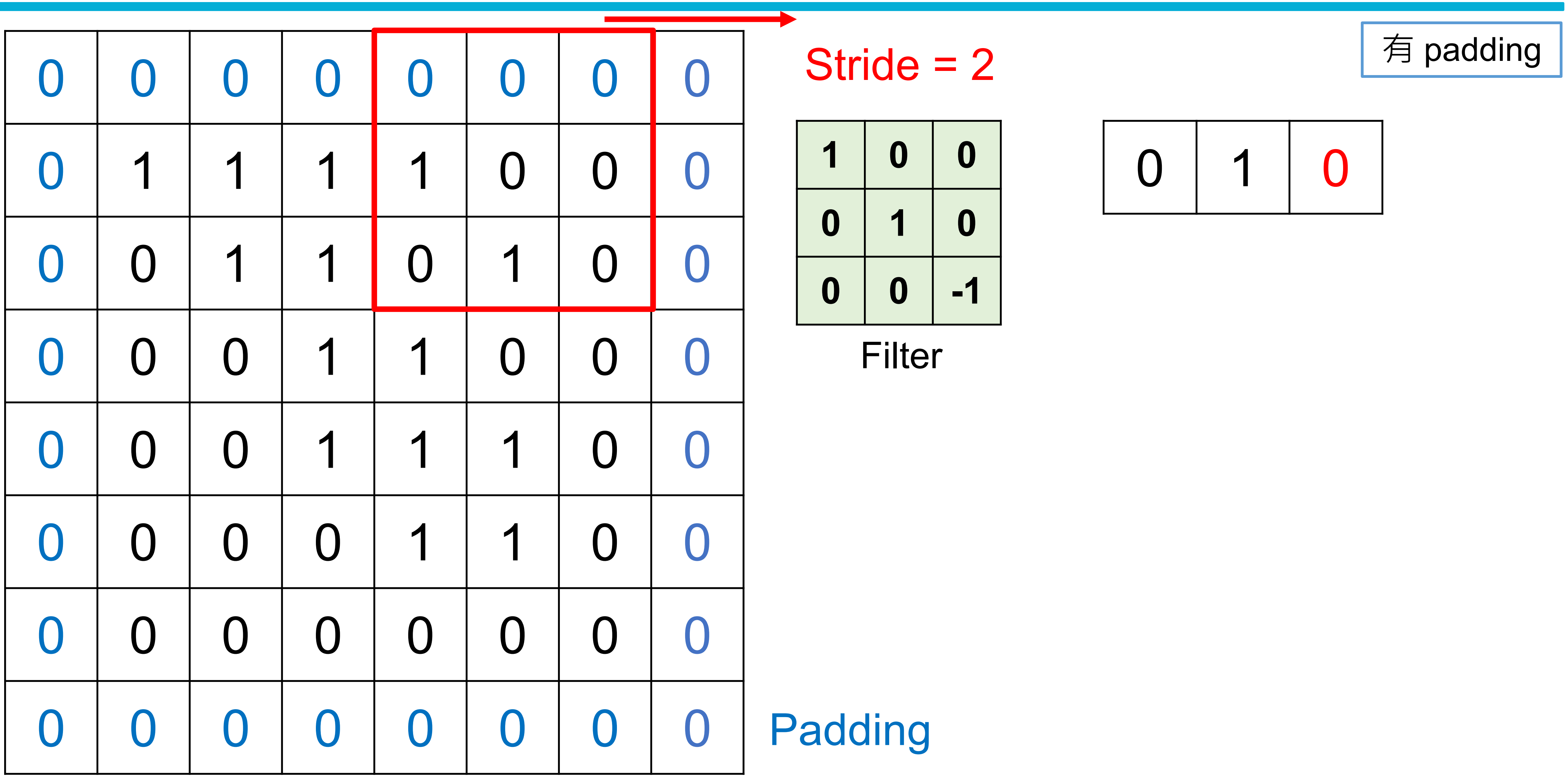
Padding

| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

| | | |
|---|---|---|
| 0 | 1 | |

# Convolutions (stride = 2, padding = 1)



Stride = 2

有 padding

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Padding

| | | |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

Filter

| | | |
|---|---|---|
| 0 | 1 | 0 |

# Convolutions (stride = 2, padding = 1)

有 padding

Stride = 2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

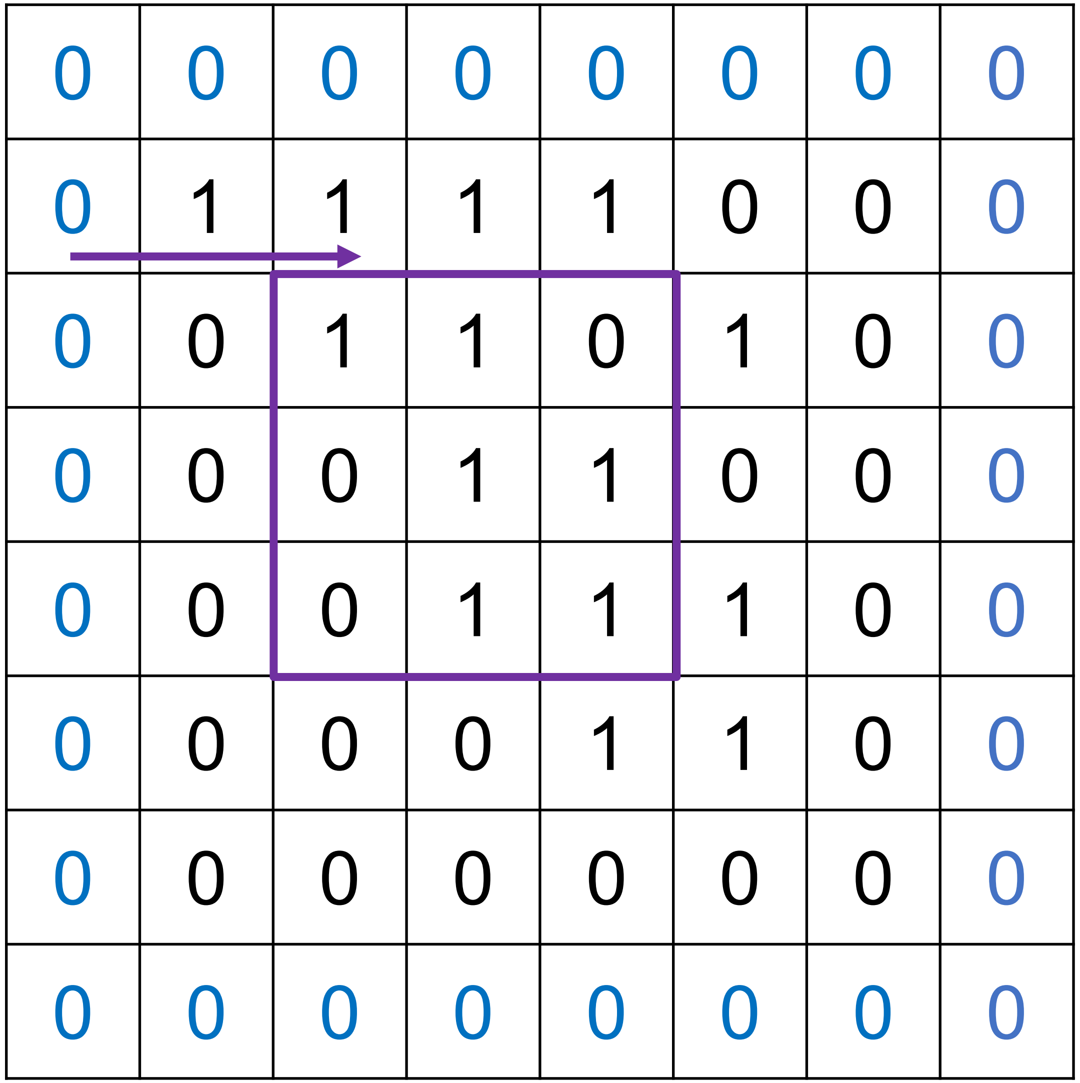
Padding

| | | |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

Filter

| | | |
|---|---|---|
| 0 | 1 | 0 |
| 0 | | |

# Convolutions (stride = 2, padding = 1)



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Padding

Stride = 2

| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

| | | |
|---|---|---|
| 0 | 1 | 0 |
| 0 | 1 | |

# Convolutions (stride = 2)

padding=1

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Padding

Stride = 2

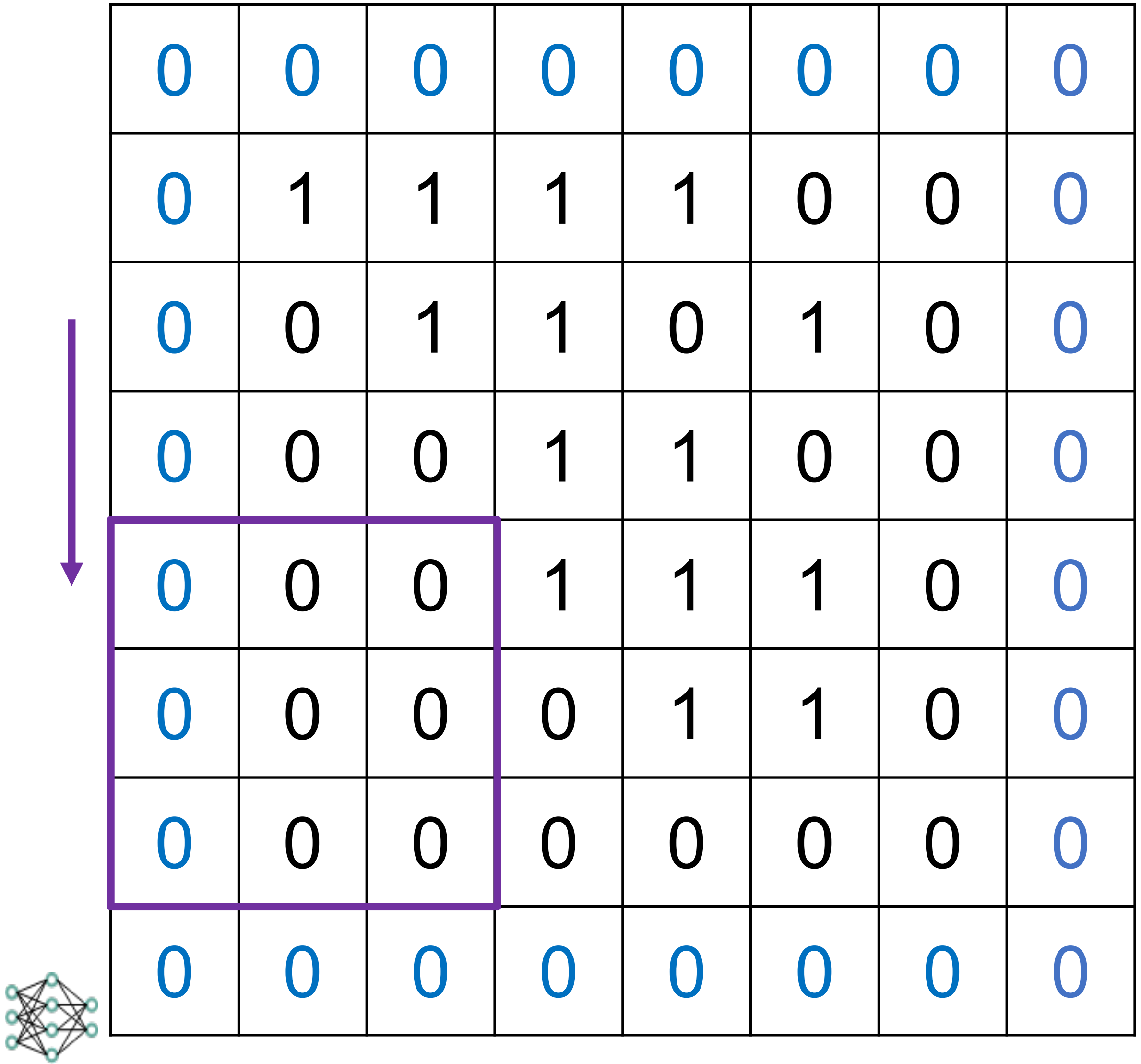
|  |  |  |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

|  |  |  |
|---|---|---|
| 0 | 1 | 0 |
| 0 | 1 | 0 |

# Convolutions (stride = 2)

padding=1



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Padding

Stride = 2

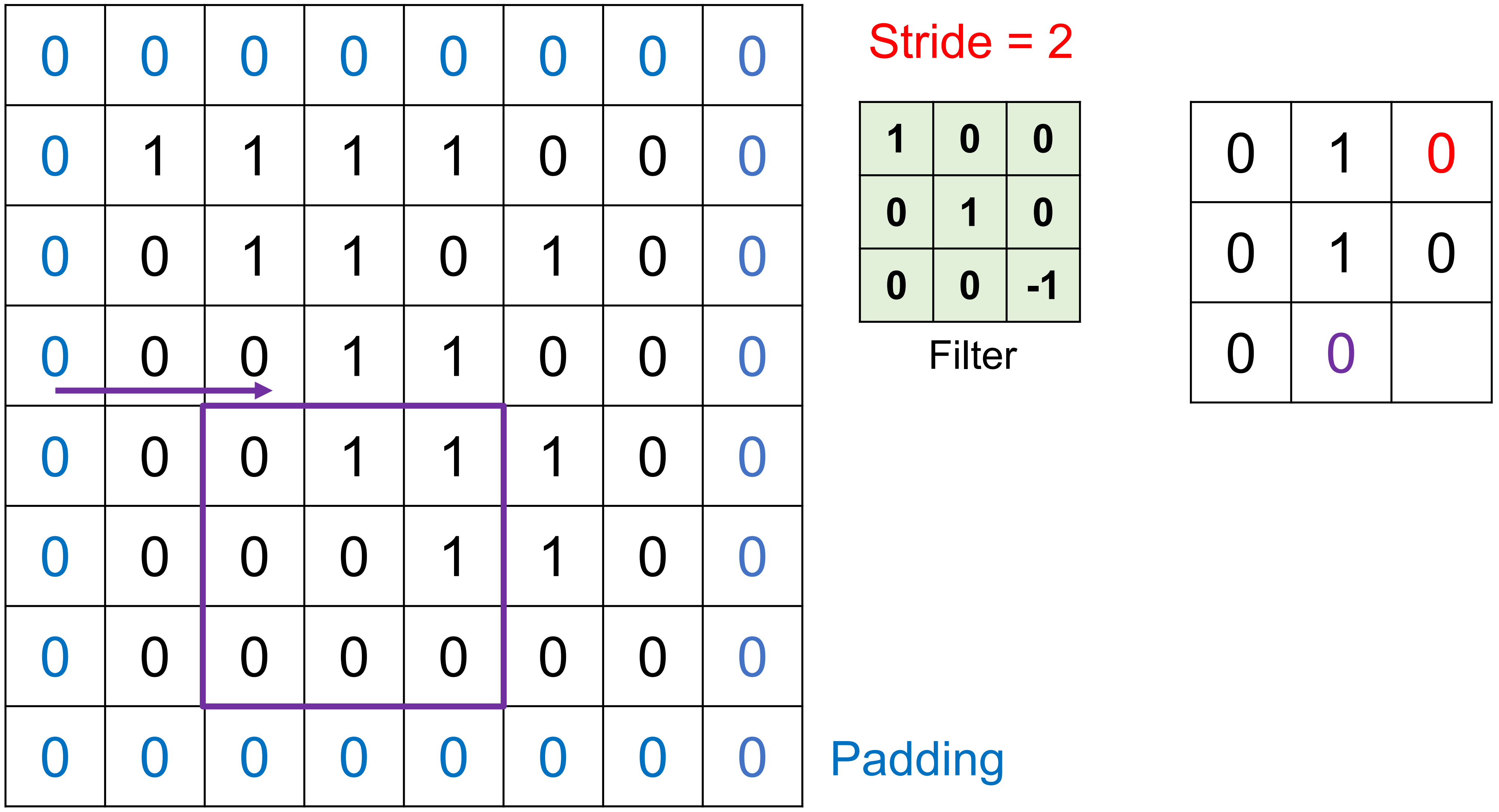
| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter

| | | |
|---|---|---|
| 0 | 1 | 0 |
| 0 | 1 | 0 |
| 0 | | |

# Convolutions (stride = 2)

padding=1



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Stride = 2

| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

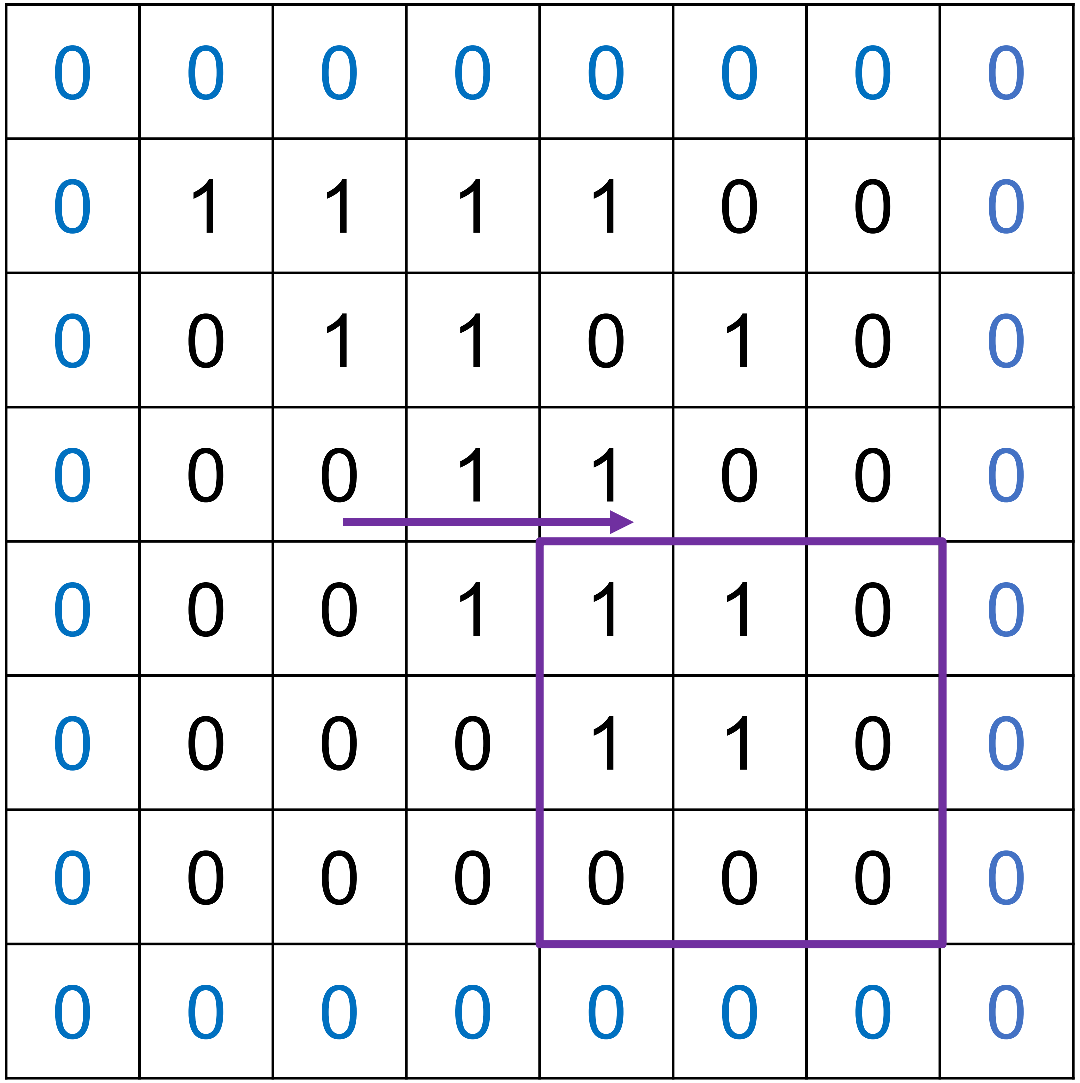
Filter

| | | |
|---|---|---|
| 0 | 1 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | |

Padding

# Convolutions (stride = 2)

padding=1



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Padding

Stride = 2

| | | |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | -1 |

Filter

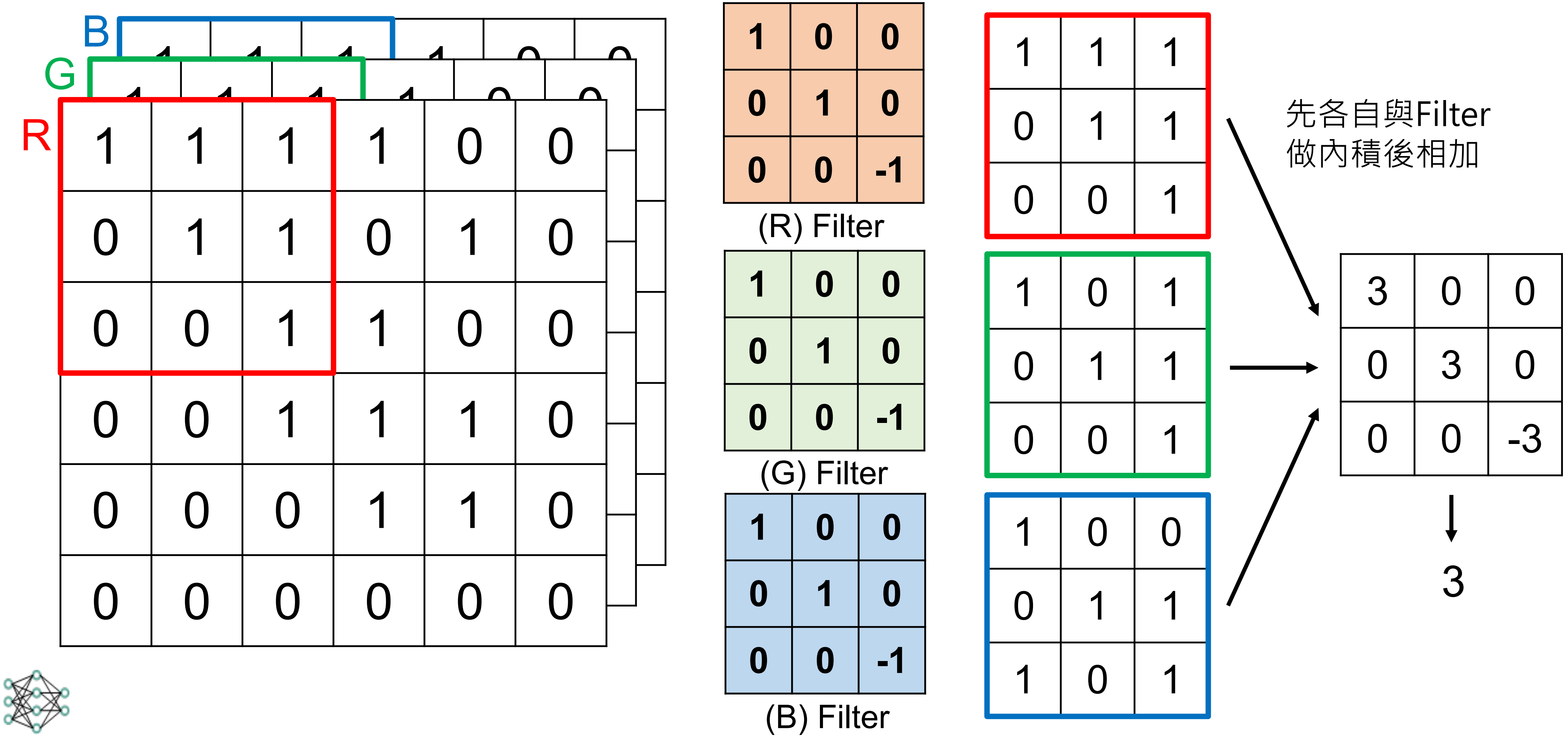
| | | |
|---|---|---|
| 0 | 1 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | 2 |

# Filters 數目與 output_channels 的關係

- Filters 的數目可以調整
- 對輸入層來說，1 個 filter 照顧 3 個 channels 的資料，輸出 1 個 feature map
- 使用 64 個 filters，就會輸出 64 個 feature maps
- 可調整參數為: num_filters * input_channels * filter_size * filter_size

# Convolutions (RGB)

filters 數值可能都是不同的！(為了方便計算，簡報使用一樣的數字)



R

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |

|  |  |  |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

(R) Filter

|  |  |  |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

(G) Filter

|  |  |  |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

(B) Filter

|  |  |  |
|---|---|---|
| 1 | 1 | 1 |
| 0 | 1 | 1 |
| 0 | 0 | 1 |

|  |  |  |
|---|---|---|
| 1 | 0 | 1 |
| 0 | 1 | 1 |
| 0 | 0 | 1 |

|  |  |  |
|---|---|---|
| 1 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |

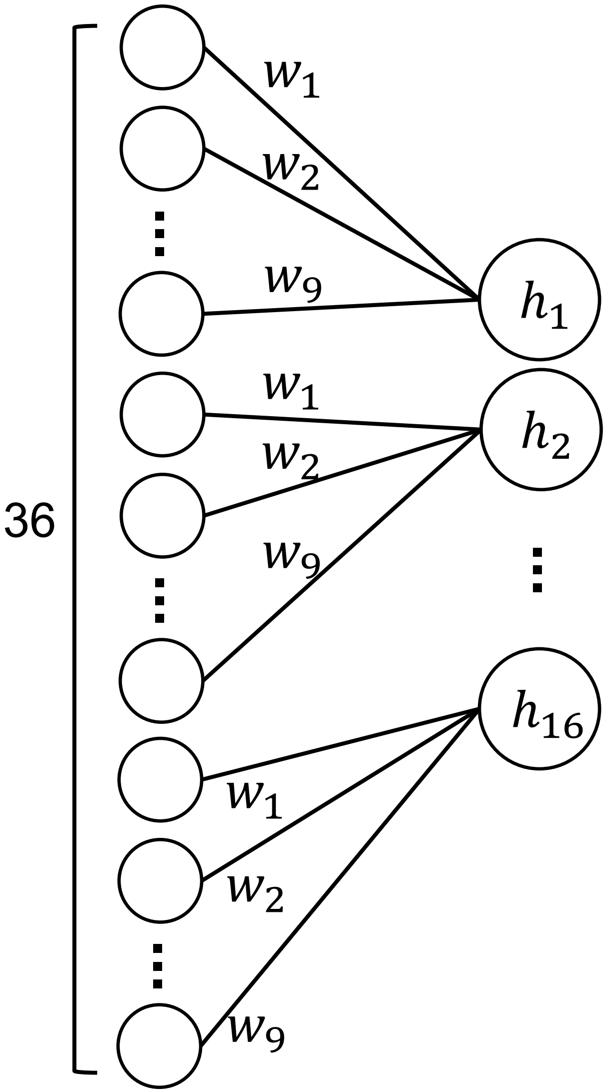
先各自與Filter
做內積後相加

|  |  |  |
|---|---|---|
| 3 | 0 | 0 |
| 0 | 3 | 0 |
| 0 | 0 | -3 |

3

# Convolutional layer is not fully-connected

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 |



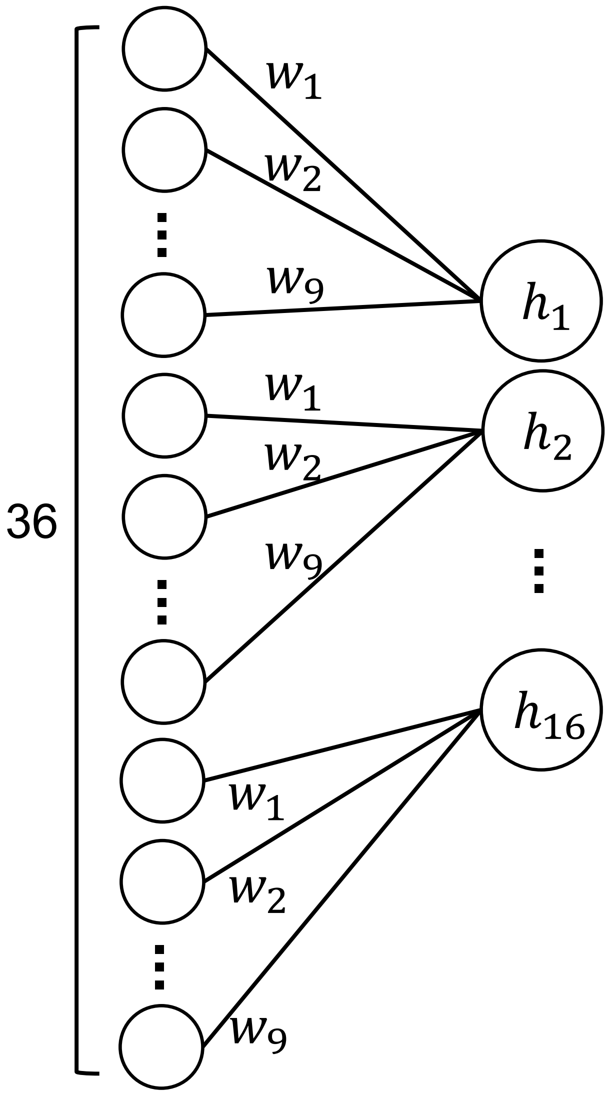
| | | |
|---|---|---|
| **1** | **0** | **0** |
| **0** | **1** | **0** |
| **0** | **0** | **-1** |

Filter, stride=1

| | | | |
|---|---|---|---|
| $h_1$ | $h_2$ | $h_3$ | $h_4$ |
| $h_5$ | $h_6$ | $h_7$ | $h_8$ |
| $h_9$ | $h_{10}$ | $h_{11}$ | $h_{12}$ |
| $h_{13}$ | $h_{14}$ | $h_{15}$ | $h_{16}$ |

feature map

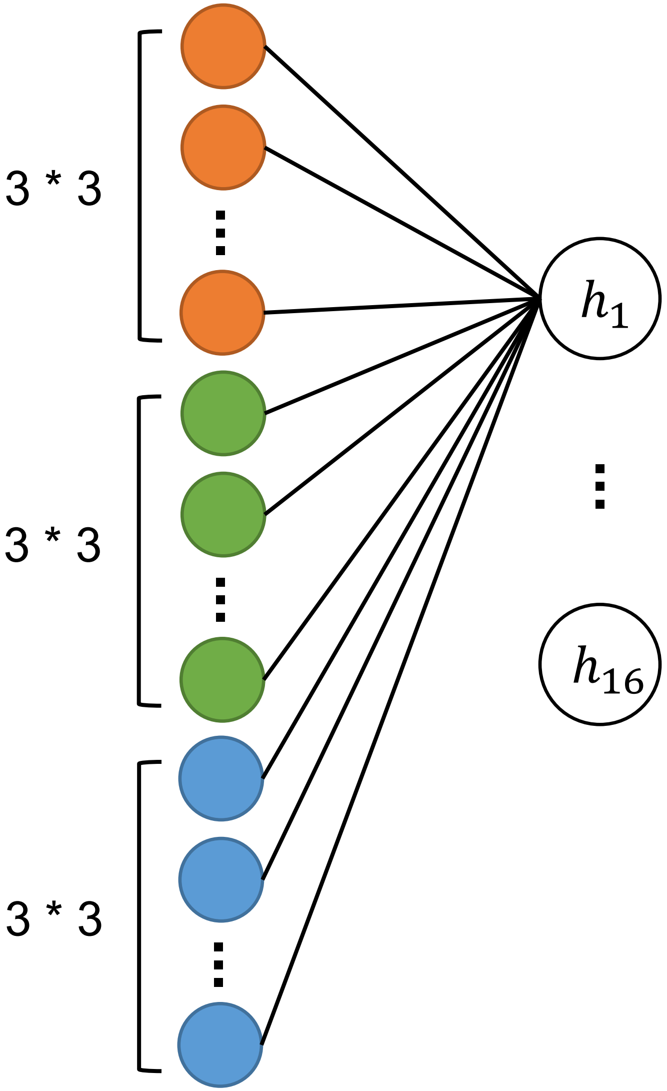
# Convolutional layer vs. FC layer 參數量



FC: fully-connected

| Grayscale images | 參數量比較 (不算 bias 數) |
|---|---|
| FC layer | 36 * 16 = 576 |
| Conv layer | 3 * 3 = 9 |

# Convolutional layer vs. FC layer 參數量

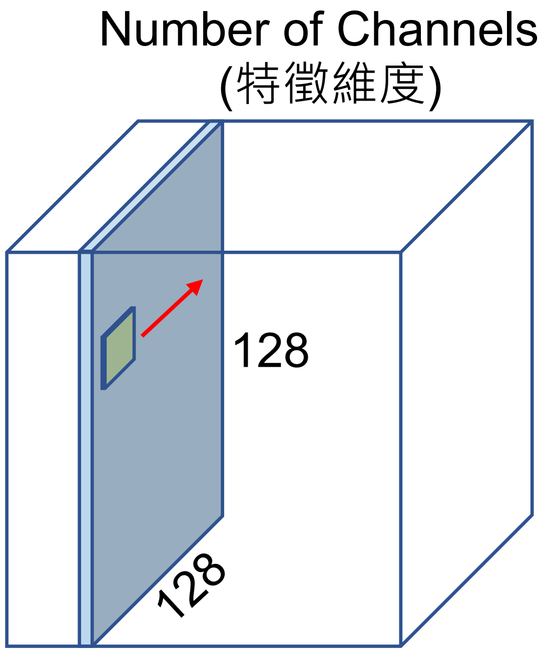


FC: fully-connected

| RGB images | 參數量比較 (不算 bias 數) |
|---|---|
| FC layer | 3 * 128 * 128 * 16 = 786,432 |
| Conv layer<br>(num_filter = 1) | 3 * 3 * 3 = 27 |
| Conv layer<br>(num_filter = 16) | 3 * 3 * 3 * 16 = 432 |

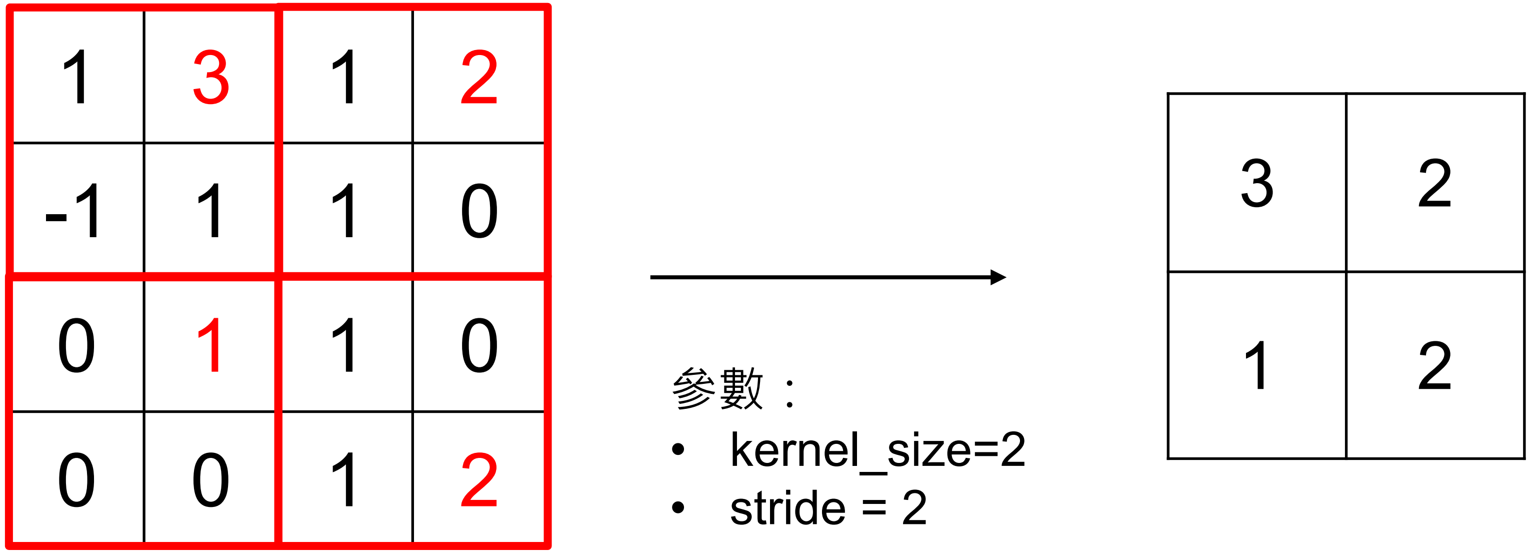
# Implementation in PyTorch

- 我們使用 `torch.nn.Conv2d`
- Why not 3d?



2d 卷積僅沿著空間維度 (Height, Width) 進行

# Pooling (example of Max Pooling)

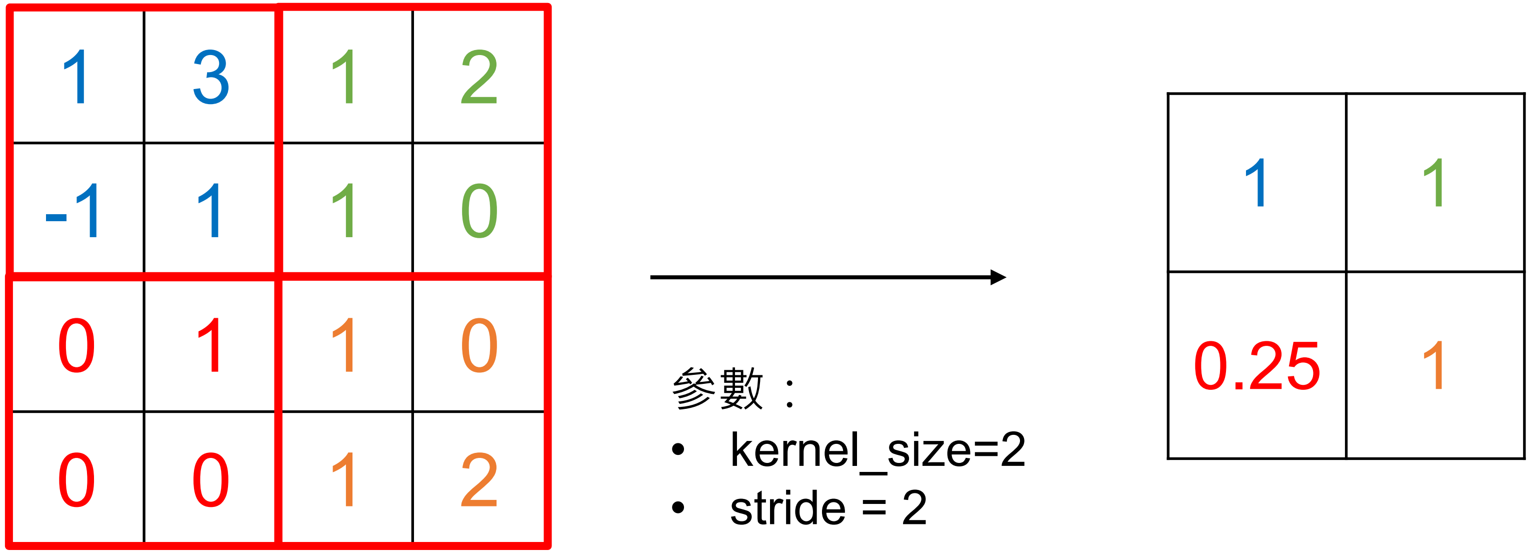


| | | | |
|---|---|---|---|
| 1 | 3 | 1 | 2 |
| -1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 |
| 0 | 0 | 1 | 2 |

參數：
- kernel_size=2
- stride = 2

| | |
|---|---|
| 3 | 2 |
| 1 | 2 |

# Pooling (example of Average Pooling)



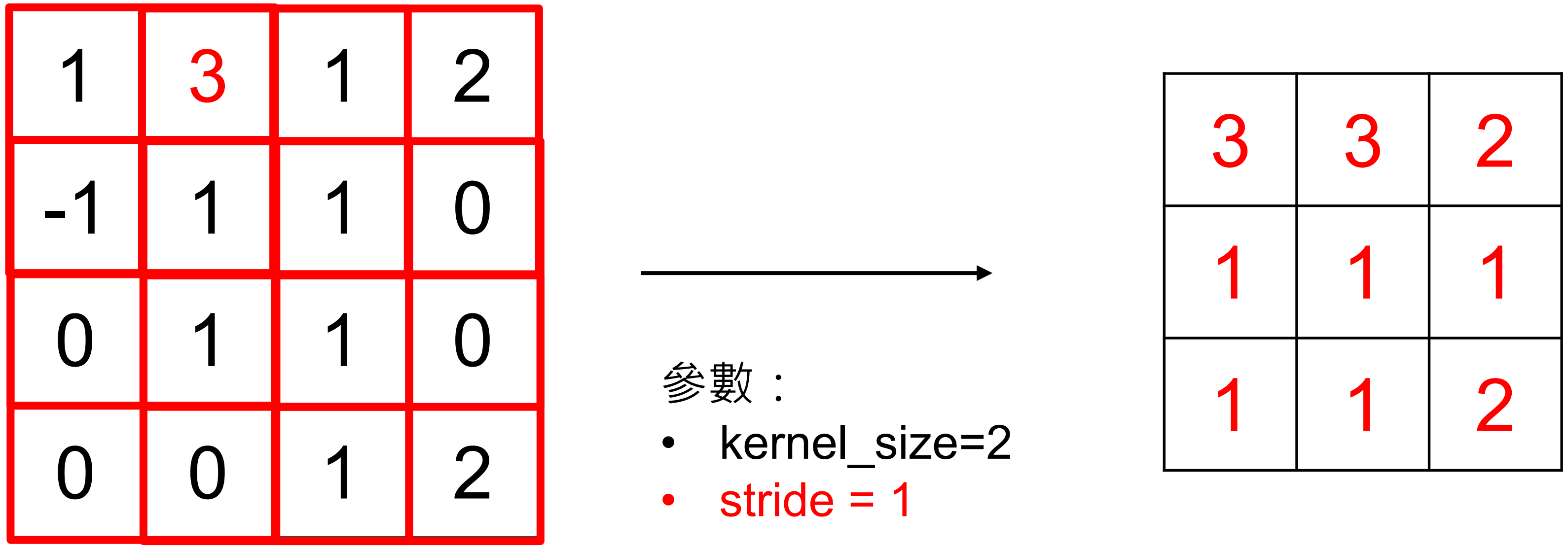
|  |  |  |  |
|---|---|---|---|
| 1 | 3 | 1 | 2 |
| -1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 |
| 0 | 0 | 1 | 2 |

參數：

- kernel_size=2
- stride = 2

|  |  |
|---|---|
| 1 | 1 |
| 0.25 | 1 |

# Pooling (example of Max Pooling)



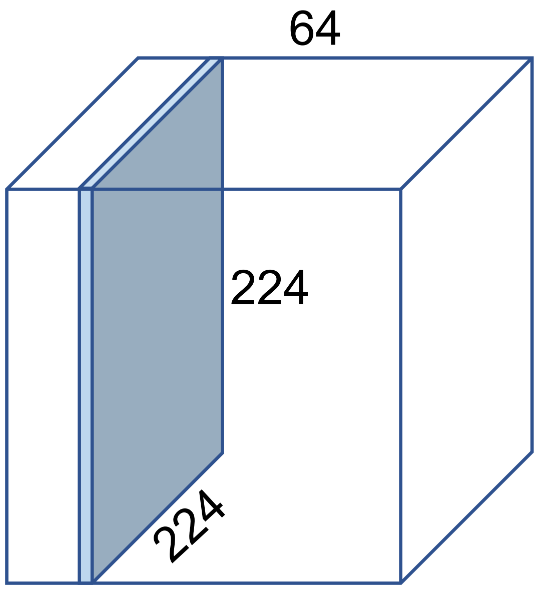
|   |   |   |   |
|---|---|---|---|
| 1 | 3 | 1 | 2 |
| -1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 |
| 0 | 0 | 1 | 2 |

參數：

- kernel_size=2
- stride = 1

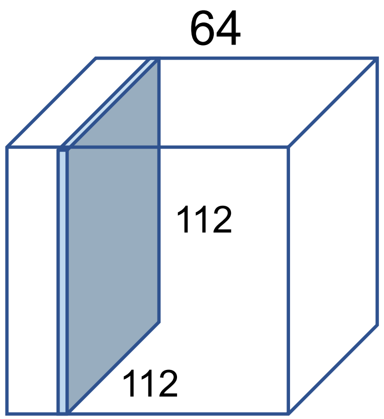
|   |   |   |
|---|---|---|
| 3 | 3 | 2 |
| 1 | 1 | 1 |
| 1 | 1 | 2 |

# 2D Pooling on RGB Images



224 x 224 x 64
(H x W x C)

參數：
- kernel_size=2
- stride = 2



112 x 112 x 64
(H x W x C)

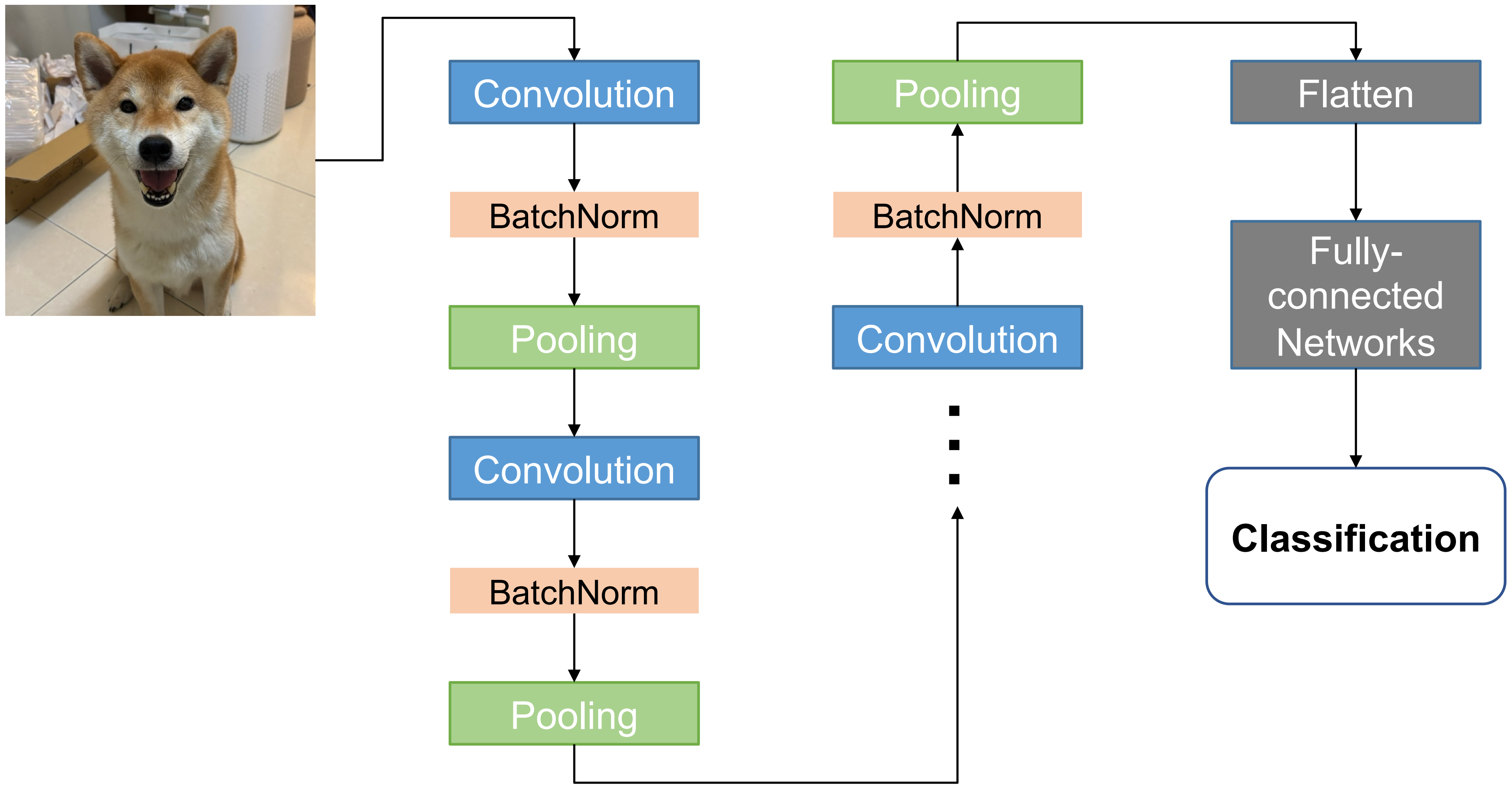
# [Important Notes] Meaning of Pooling

- To maintain the most relevant information
  - Summarizing the features within the region covered by the filter
- Shortage:
  - No theoretical guarantee for making better model performance

# CNN 的結局

- 通常不會只有一層的 Convolutional Layer
- 隨著層數增加，通常 Feature map 會越來越小，因為：
  - Convolutional Layer 可能會縮小 feature map (如果沒有 padding)
  - Pooling 也會縮小 feature map
- 經過了多次的 Convolution + Pooling 後的 feature map 為壓縮後的**重要資訊**

# The whole CNN



Convolution

BatchNorm

Pooling

Convolution

BatchNorm

Pooling

Convolution

BatchNorm

Pooling

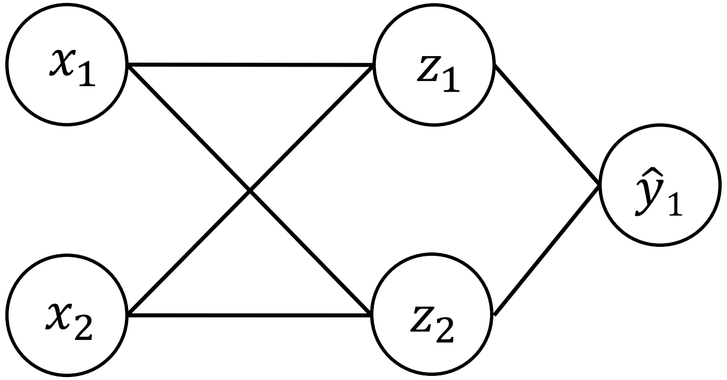
Flatten

Fully-connected Networks

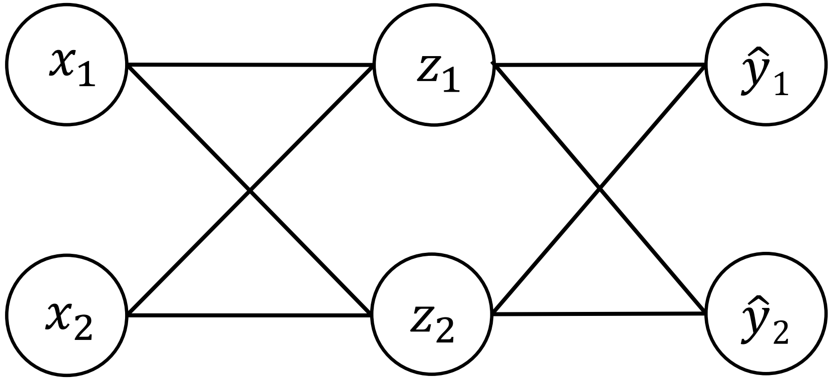
**Classification**

# Fully-connected Networks

- 常被稱為全連接層 (Fully-connected layers, FC)
- Multi-layer perceptron (MLP) 即是由 FC 所構成
- 注意! CNN 不是全連接層



Regression / Binary Classification



Classification

# Why Flatten?

- 以分類任務來說，我們需要 Fully-connected layers
- CNN 常被用於分類任務

# CNN Summary

- 為影像資料量身定做，用來捕捉空間資訊 (Spatial Information)
- Parameter sharing (參數共享機制)
  - 降低用 MLP 來進行影像任務的參數量

# ConvNets are everywhere

### Object Detection with YOLO

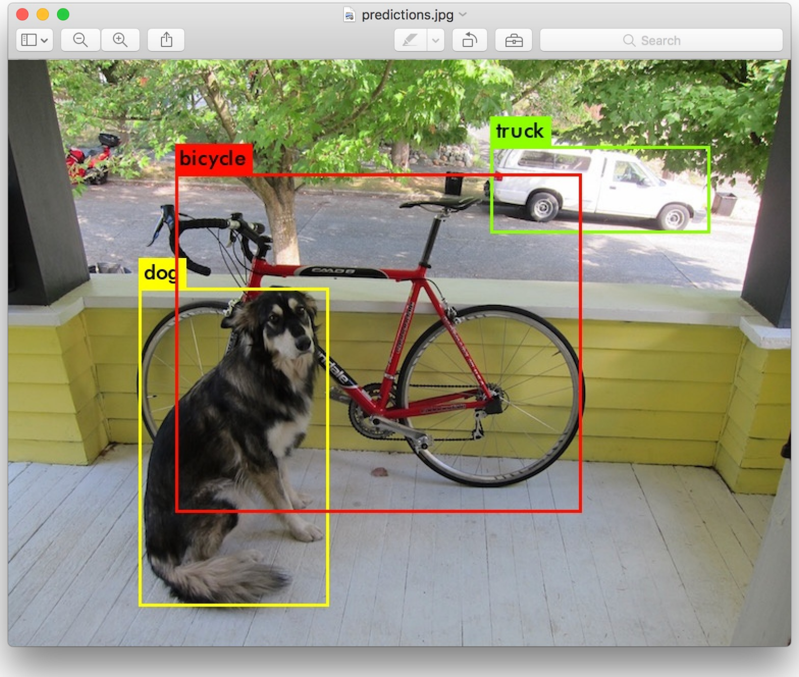


Figure source: https://pjreddie.com/darknet/yolo/

### Style Transfer with CNN

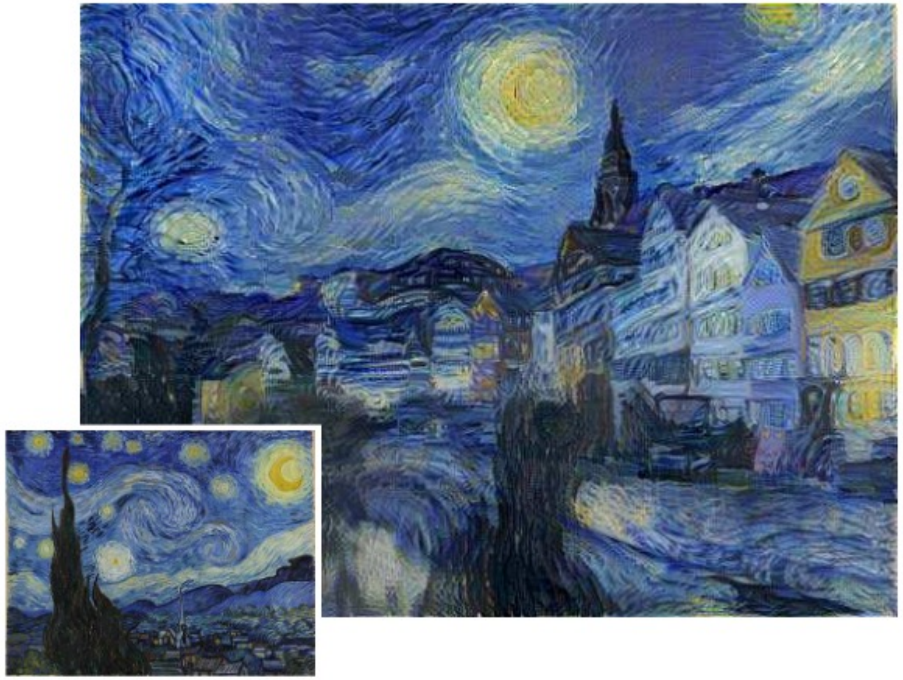


Figure source: Gatys, Leon A., Alexander S. Ecker, and Matthias Bethge. "Image style transfer using convolutional neural networks." CVPR. 2016.

# Advanced CNNs

- [ResNet] Deep Residual Learning for Image Recognition
  - https://arxiv.org/abs/1512.03385
- [DenseNet] Densely Connected Convolutional Networks
  - https://arxiv.org/abs/1608.06993
- https://slazebni.cs.illinois.edu/spring17/lec04_advanced_cnn.pdf

# Additional Links

- **PyTorch CNN example**:
  https://pytorch.org/tutorials/beginner/blitz/cifar10_tutorial.html
- **Batch Normalization:**
  - https://wandb.ai/wandb_fc/GroupNorm/reports/Group-Normalization-in-Pytorch-With-Examples---VmlldzoxMzU0MzMy
  - https://towardsdatascience.com/batch-norm-explained-visually-how-it-works-and-why-neural-networks-need-it-b18919692739/

# Thank you!

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