

# **Neural Networks for Computer Vision**

An introduction

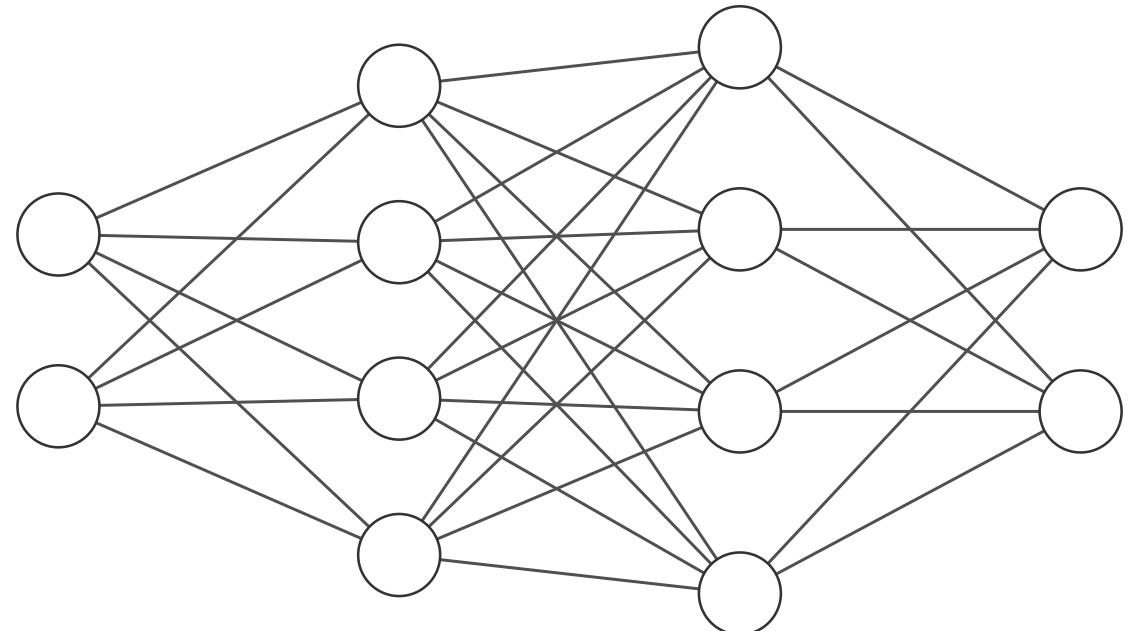
# Contents

1. From simple perceptrons to complex architectures
2. Adapting neural networks to images
3. Training a model

# Multi Layer Perceptron

From perceptron to MLP : stack perceptron to create a network

- An universal approximator
- An example



Input Layer  $\in \mathbb{R}^2$

Hidden Layer  $\in \mathbb{R}^4$

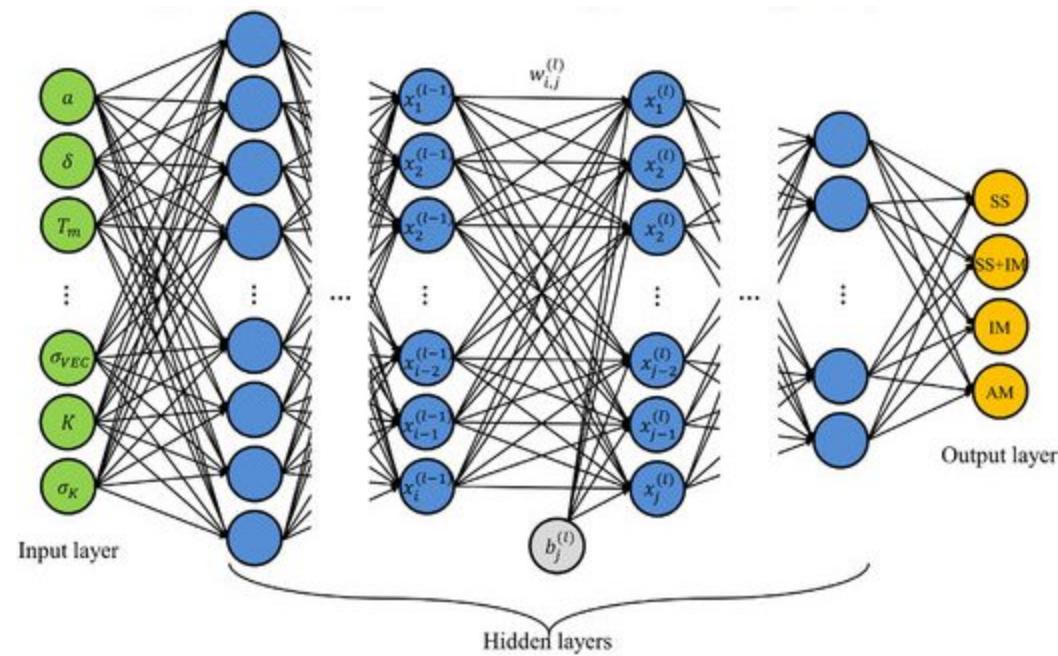
Hidden Layer  $\in \mathbb{R}^4$

Output Layer  $\in \mathbb{R}^2$

# The Deep in Deep Learning

- Deep : many layers
- Wide : many neurons

The more layers, the more complex the function can be, the more data needed to train



# Convolutional Neural Networks

MLP are designed for tabular data,  
not for images

- No translation invariance
- No spatial invariance

Images have structure, and we  
want to exploit it



Output  $f(x) = 1$

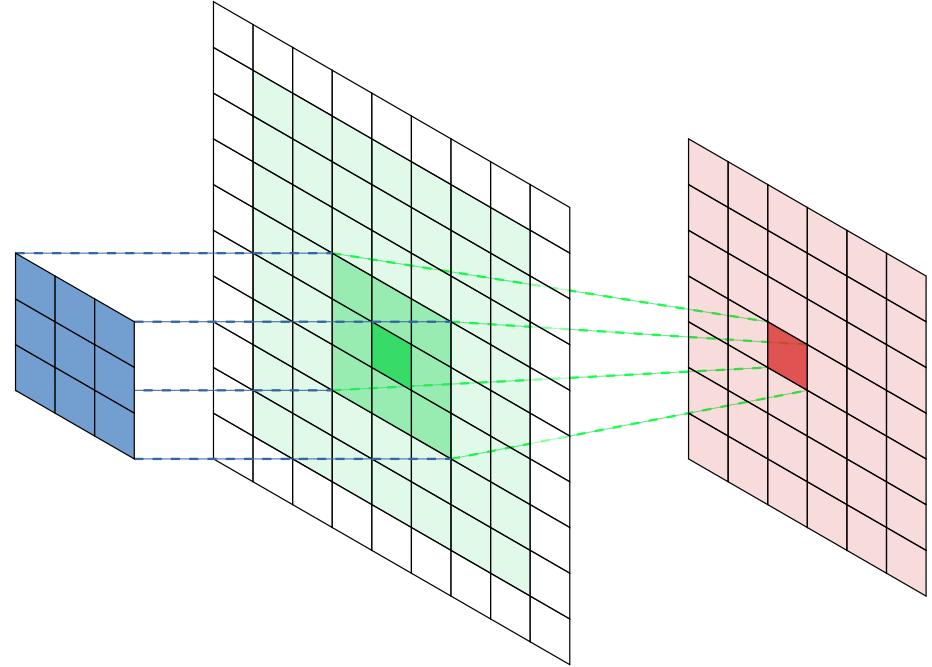


Output  $f(S_v x) = 1$

# CNNs

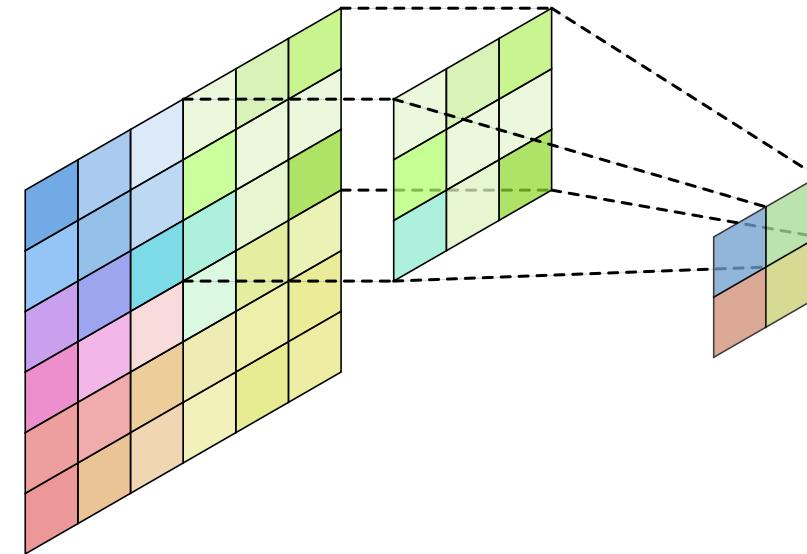
## Convolutional Layers

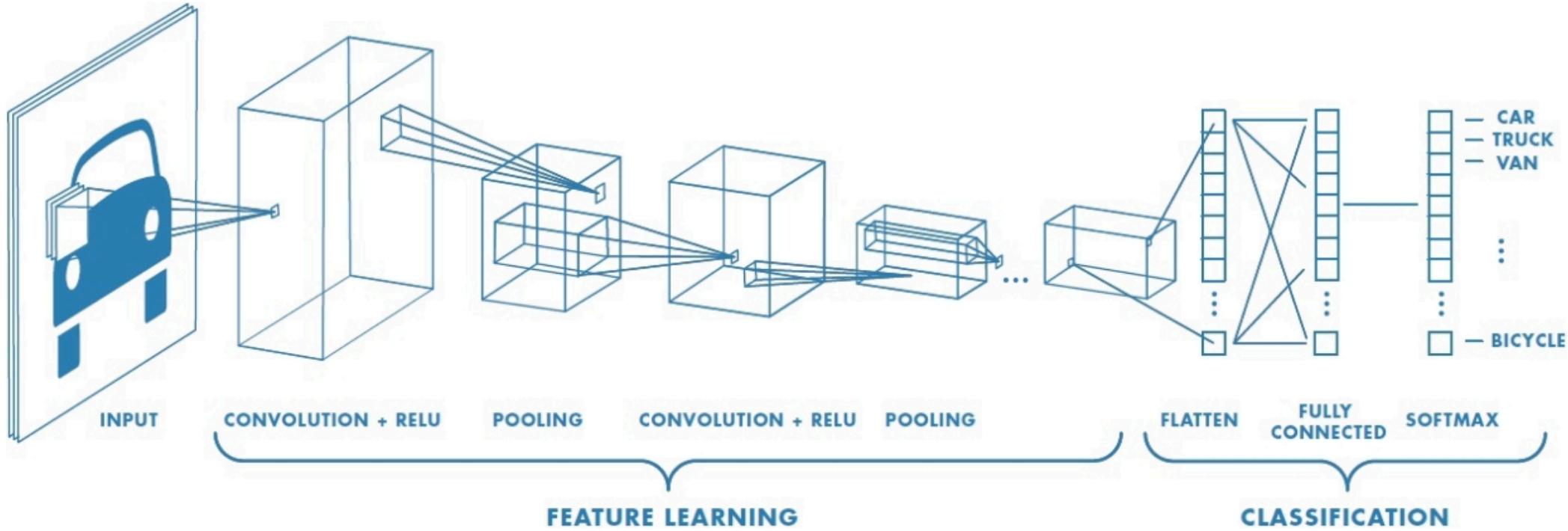
Centered on a pixel, apply a (learnt) filter



## Pooling Layers

Reduce the size of the image, keep the most important information





# Benefits of CNNs

- Translation invariance
- Spatial invariance
- Fewer parameters
- Hierarchical features

Let's see

# Tasks in Computer Vision

Considering images, we can have different tasks :

- Image Classification
- Object Detection
- Semantic Segmentation
- ...

Everything is how to define the problem

# Image Classification

Given an image, predict what is in it

$$\text{Image} \rightarrow \mathbb{N}$$

exemple : ImageNet, CIFAR-10, MNIST

**airplane**



**automobile**



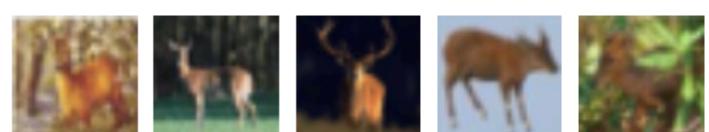
**bird**



**cat**



**deer**



**dog**



**frog**



**horse**



**ship**



**truck**

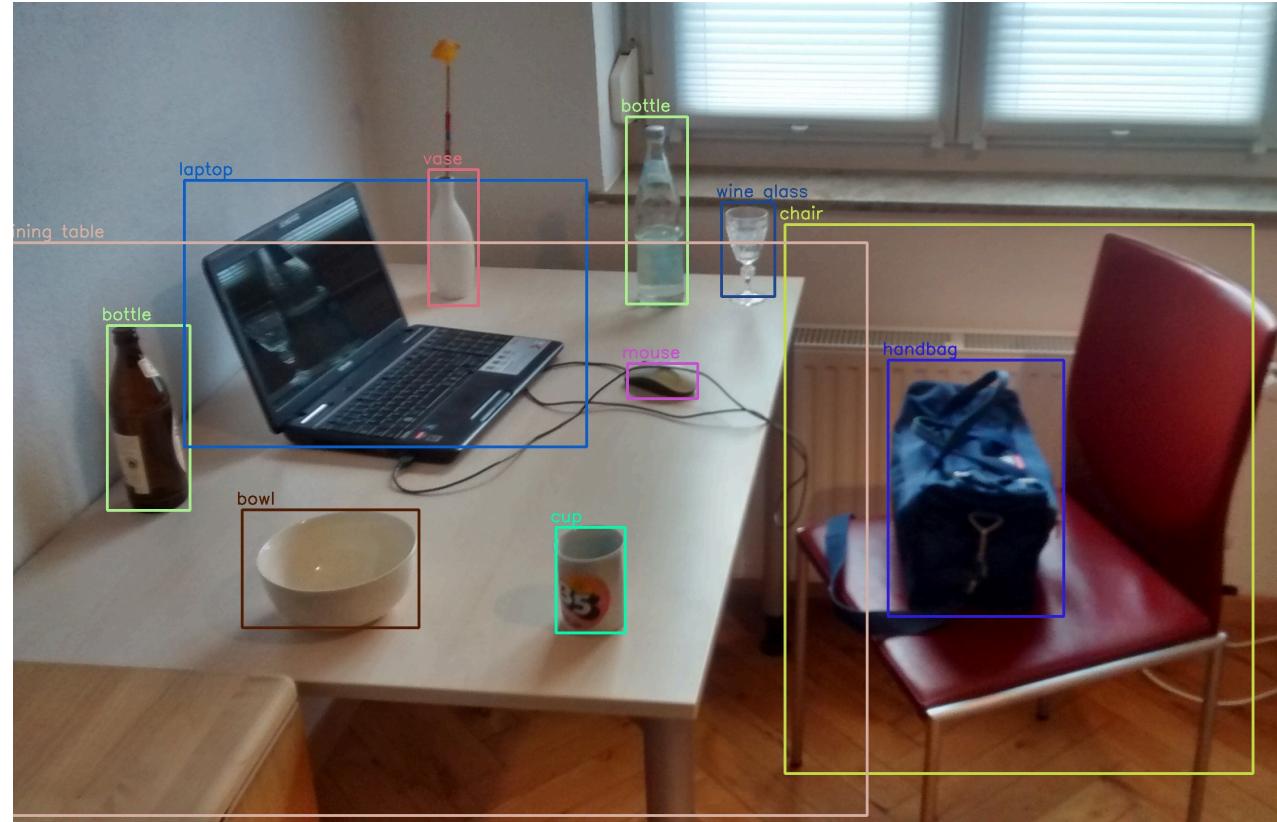


# Object Detection

Given an image, predict what is in it, and where

$$(\text{Image} \rightarrow \mathbb{N}) \times (\text{Image} \rightarrow \mathbb{R}^4)$$

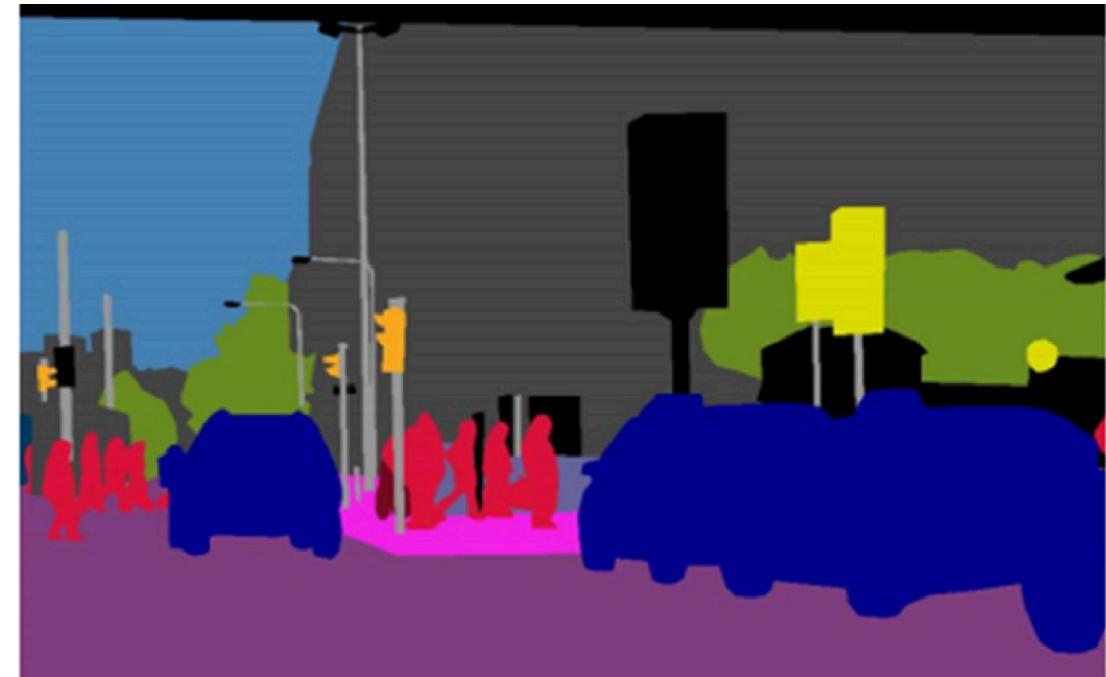
example : YOLO, COCO, VOC



# Semantic Segmentation

Given an image, predict for each pixel, what is the class

$$\text{Image} \rightarrow \mathbb{N}^{\text{width} \times \text{height}}$$



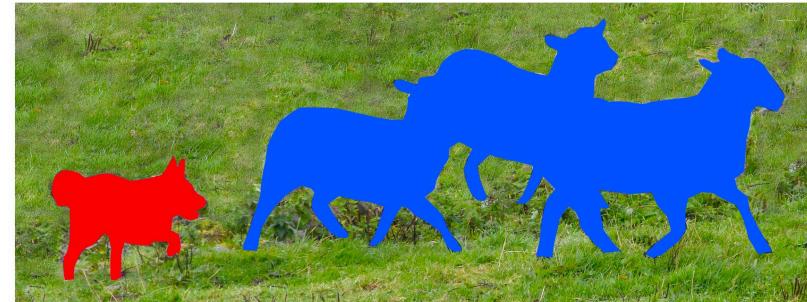
# Instance Segmentation

Given an image, predict for each pixel, what is the class, and to which instance it belongs

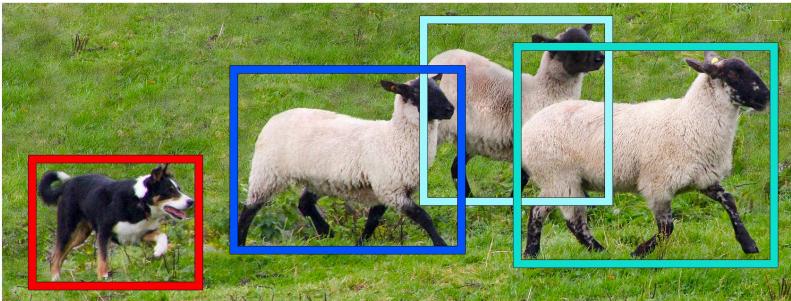
$$\text{Image} \rightarrow \mathbb{N}^{\text{width} \times \text{height}} \times \mathbb{N}^{\text{width} \times \text{height}}$$



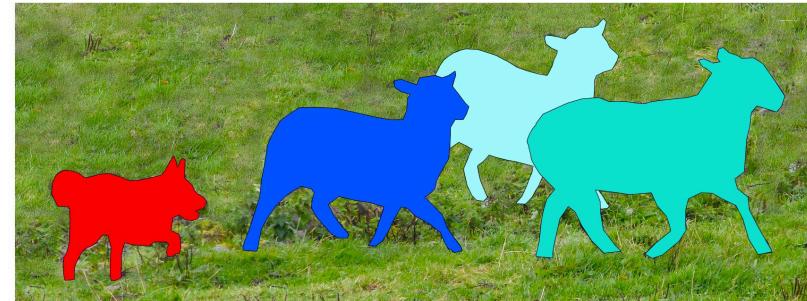
Image Recognition



Semantic Segmentation



Object Detection



Instance Segmentation

# Image Generation

Given a text, generate an image

→ Image

example : DALL-E, midjourney,



# Applications of Neural Networks in Computer Vision

- Medical Imaging
- Autonomous Vehicles
- Robotics
- ...

Different tasks, different architectures

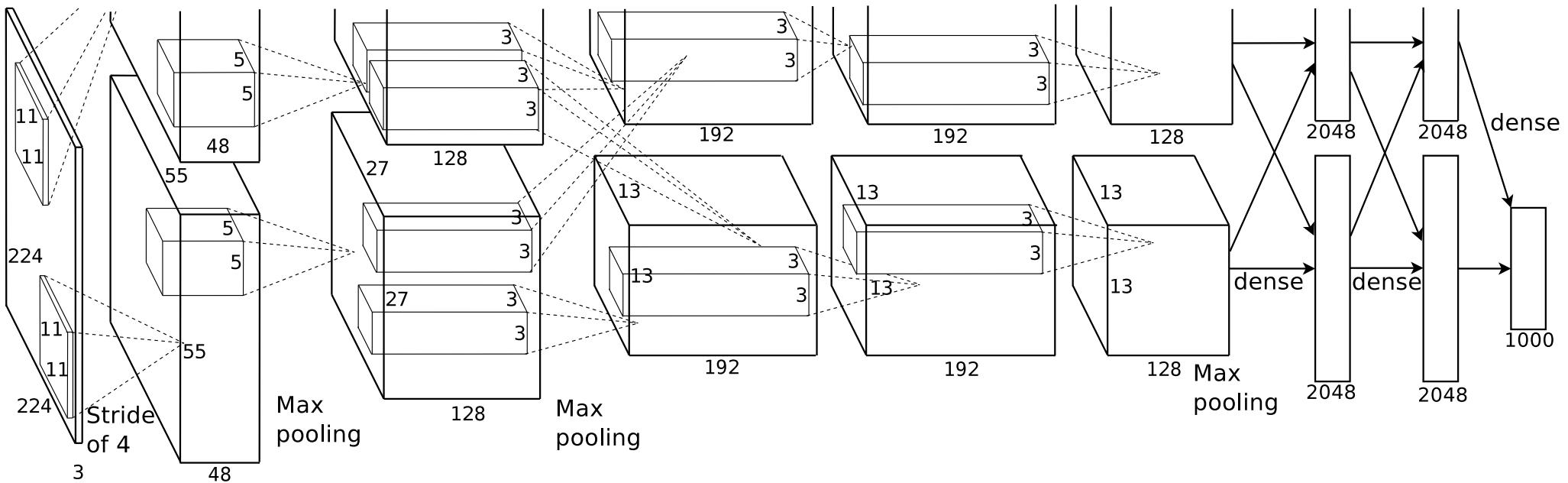
# Well known architectures

A diverse set of architectures have been developed over the years

# AlexNet

2012

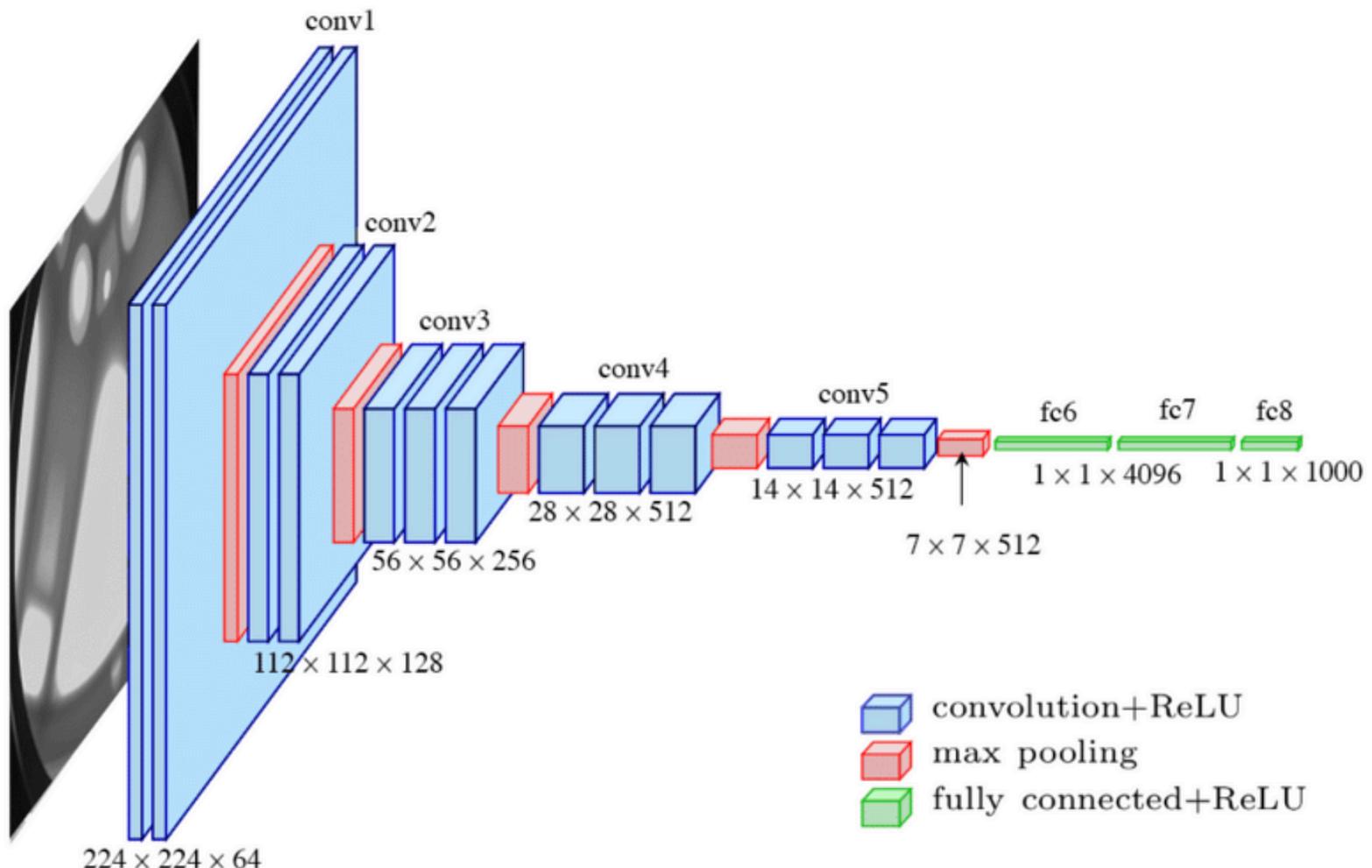
Historical architecture, first to use CNNs for ImageNet



# VGG

2014

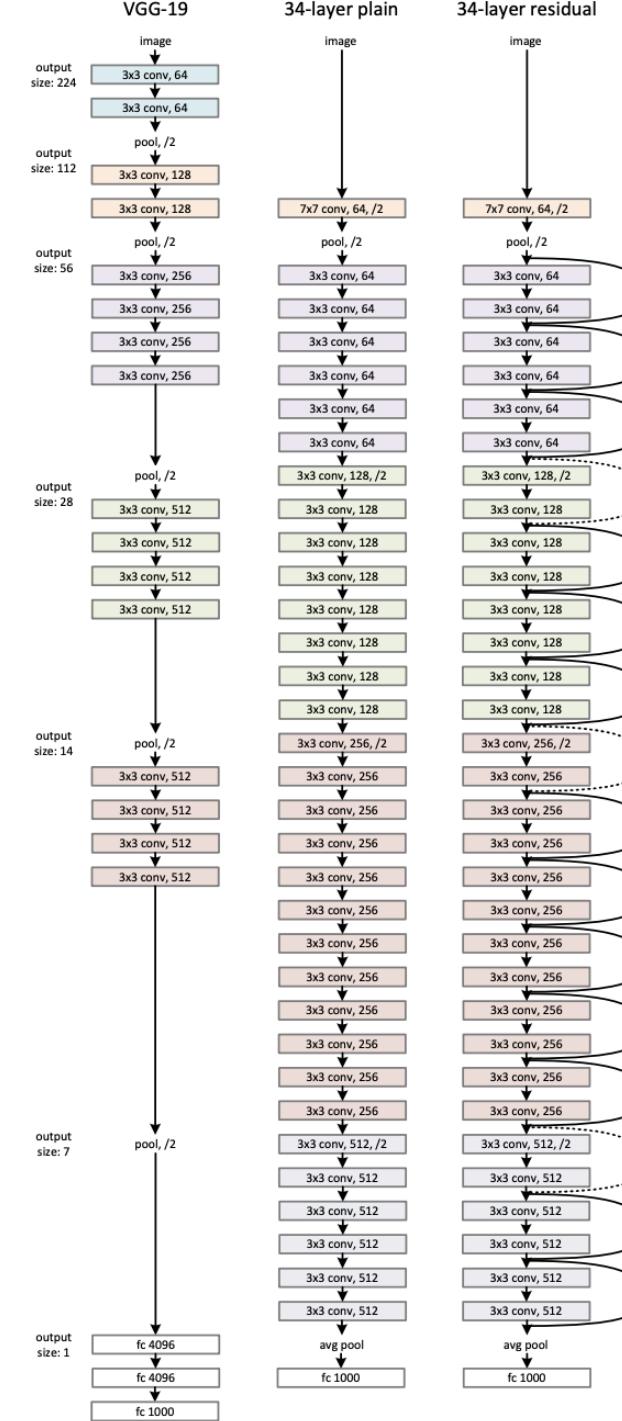
Very deep architecture, 16 or 19 layers



# ResNet

2015

Residual connections, allows to  
train very deep networks

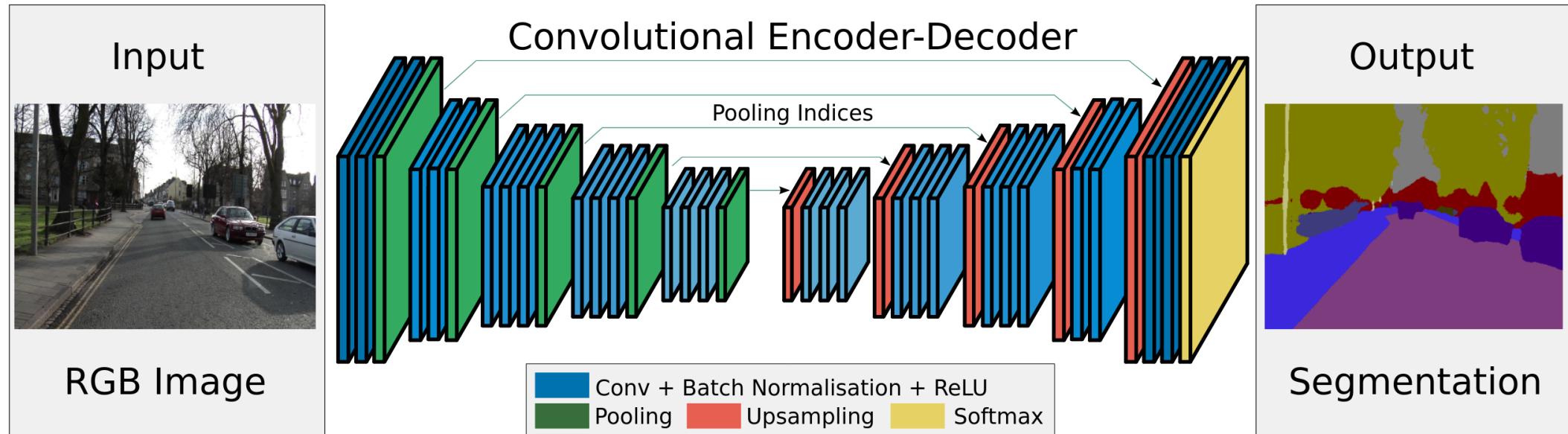


# U-Net

2015

For segmentation tasks

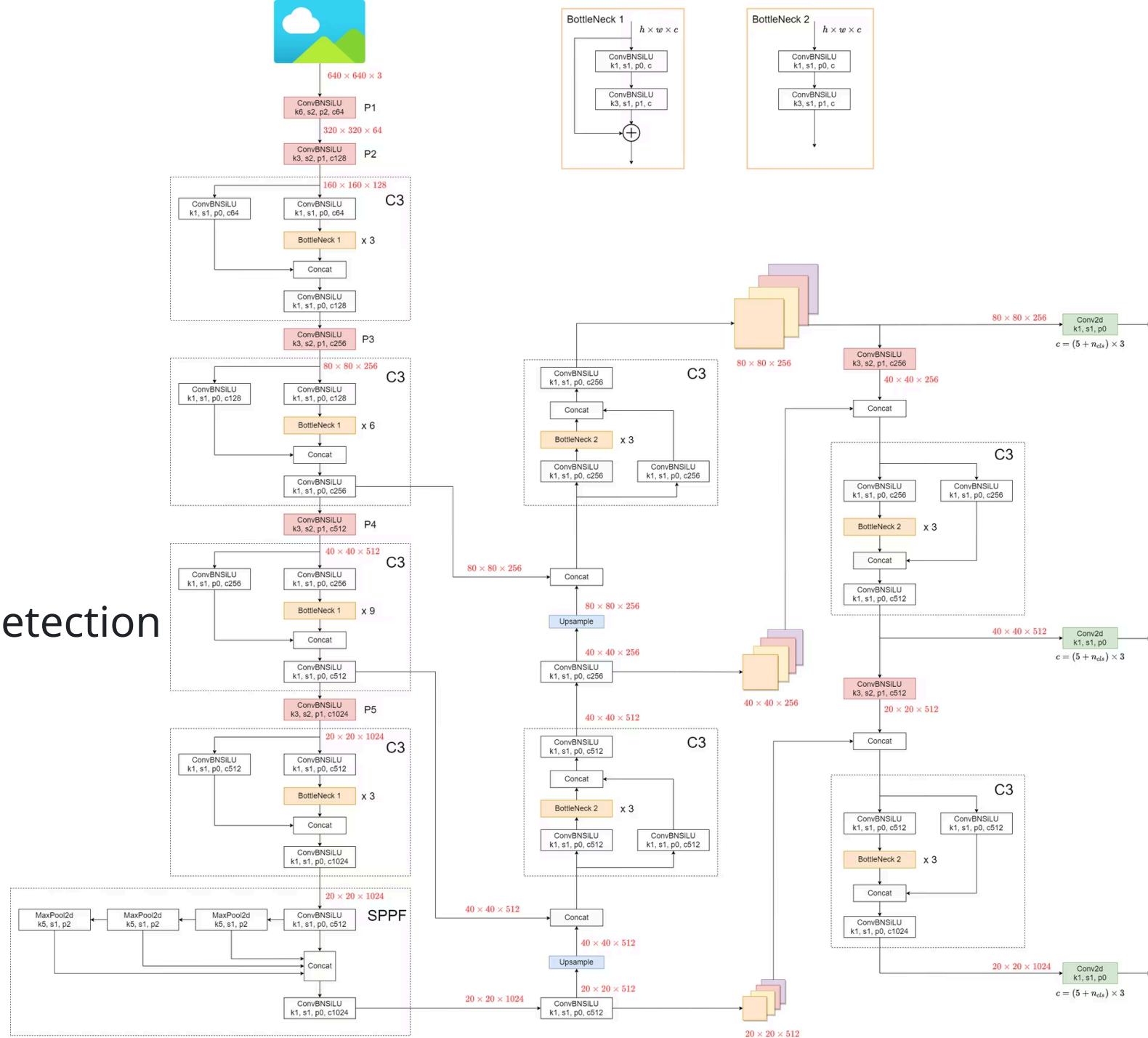
4



# YOLO

2016

For object detection



# **First Conclusion**

Neural Networks are a powerful tool for Computer Vision

They can be used for a wide range of tasks

Next question : how to train them?

# How deep learning models learn ?

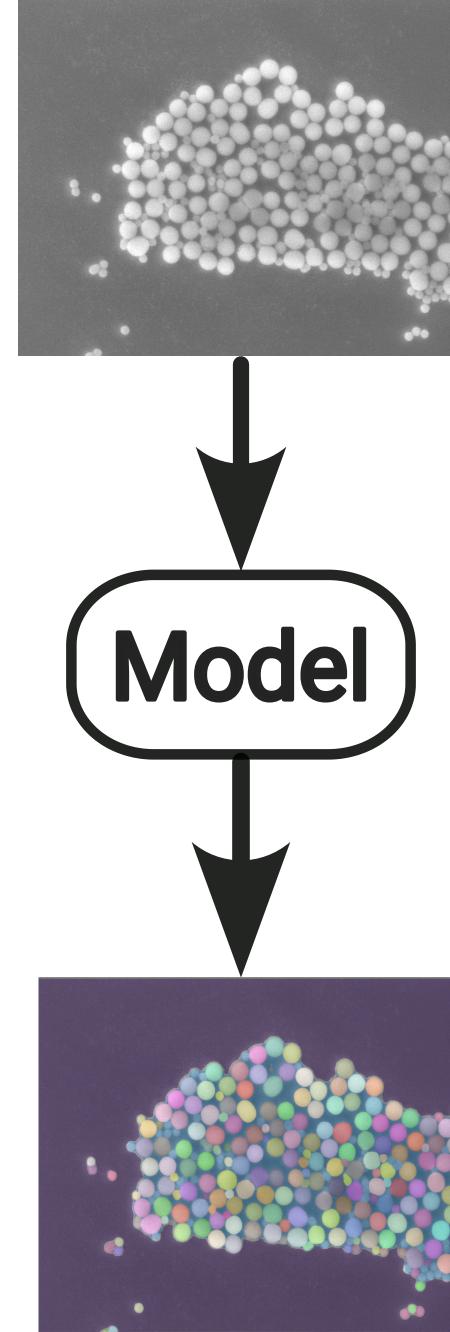
# A deep learning model

A deep learning model is a function  
that maps an input to an output

$$f : \mathcal{X} \rightarrow \mathcal{Y}$$

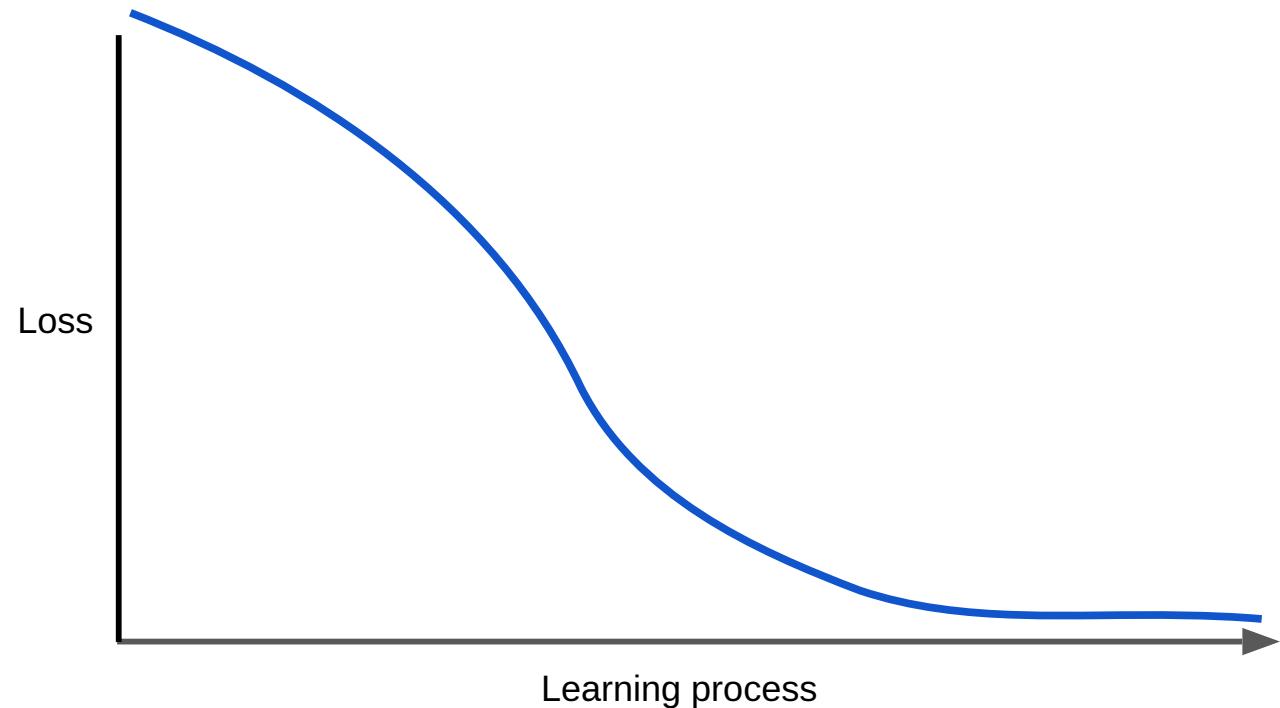
## Example

- The input is an image
- The output is a pixel class prediction
- The model is parametrized by weights



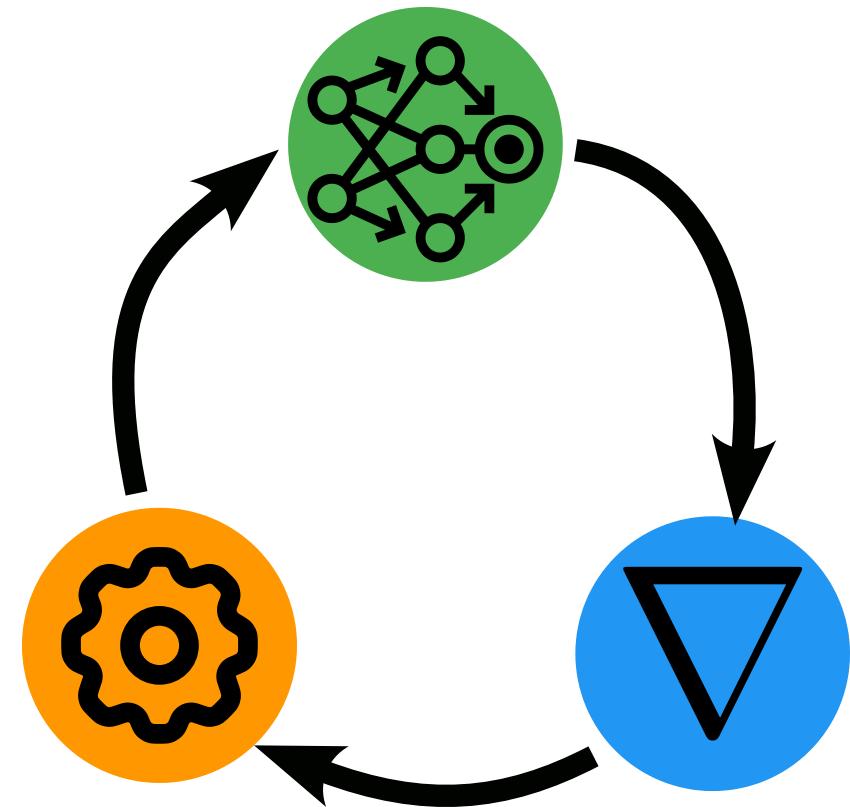
# Learning Process

- Deep Learning models learn by **minimizing a loss function**
- The loss function measures how well the model is performing
- Weights are updated to minimize the loss function
- $\mathbb{R}^{width \times height} \rightarrow \mathbb{R}$



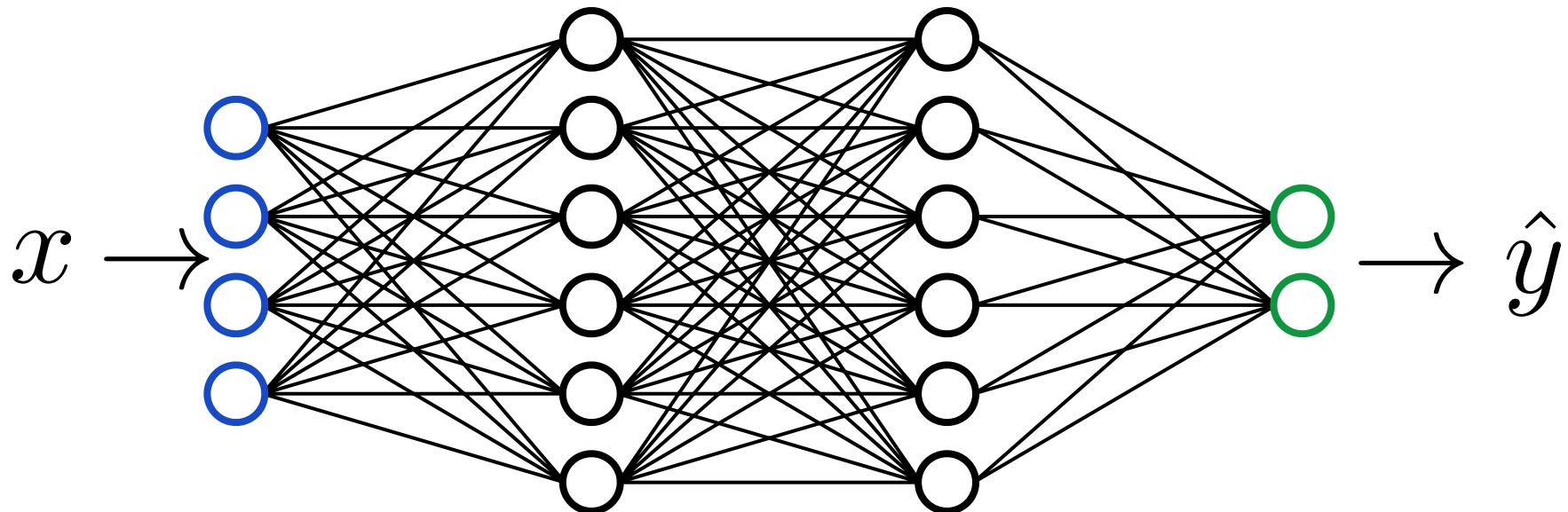
## Learning iteration

- **Feed Forward** : Compute the output of the network
- **Backpropagation** : Calculate the gradients
- **Optimizer** : Update the weights



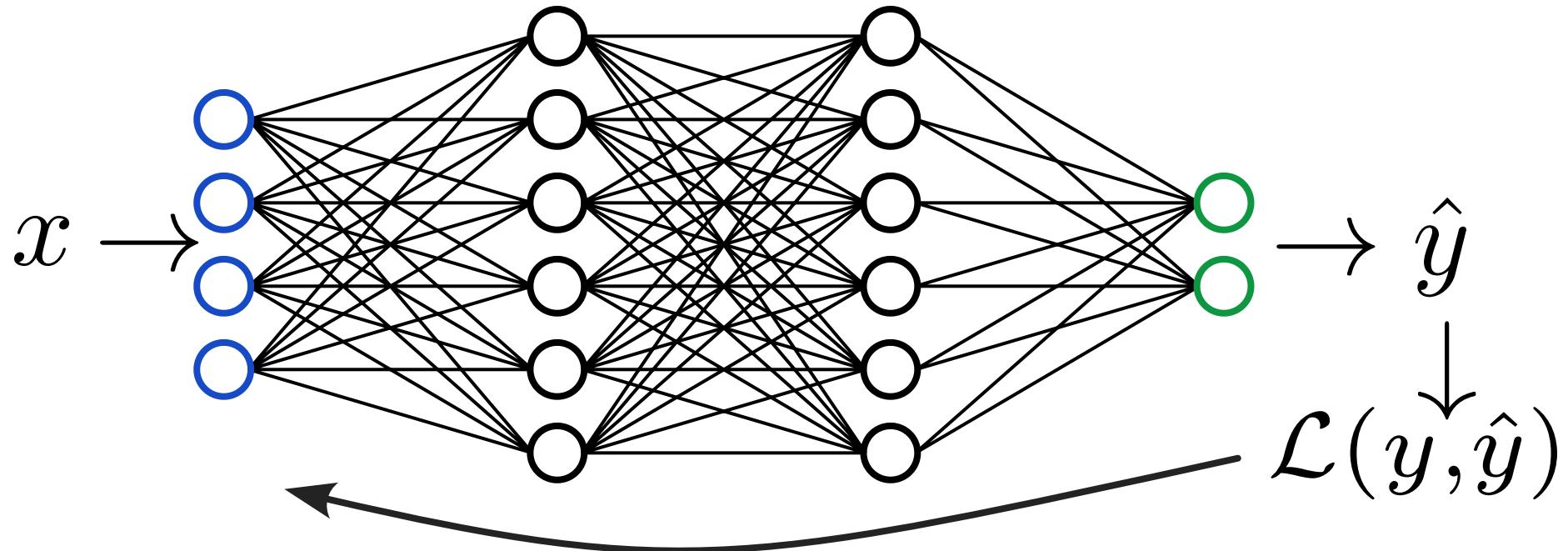
## Feed Forward

- **Feed Forward** is the process of computing the output of the network



# Backpropagation

- **Backpropagation** is the process of calculating gradients
- According to the loss function



$$\frac{\partial \mathcal{L}(y, \hat{y})}{\partial w}$$

# Optimizer

$$w_{k+1} \leftarrow w_k - \alpha_k \frac{\partial L(y, \hat{y})}{\partial w_k}$$

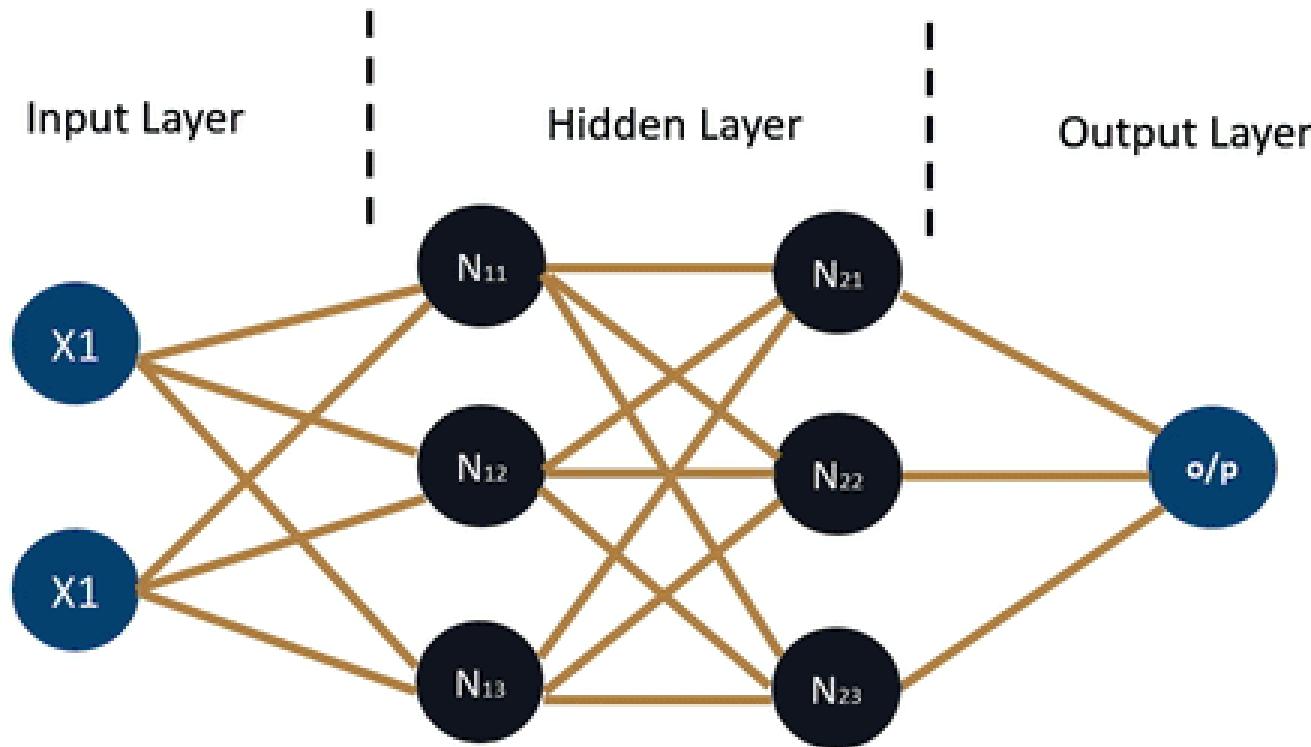
## Key Terms:

- $w_k$ : Current weights
- $\alpha_k$ : Learning rate
- $\frac{\partial L(y, \hat{y})}{\partial w_k}$  : Gradient of the cost function

## Dynamics of Learning:

- **Step Direction** : Show how the weights are updated iteratively.
- **Learning Rate Impact** : Too high → Oscillation; Too low → Slow convergence.

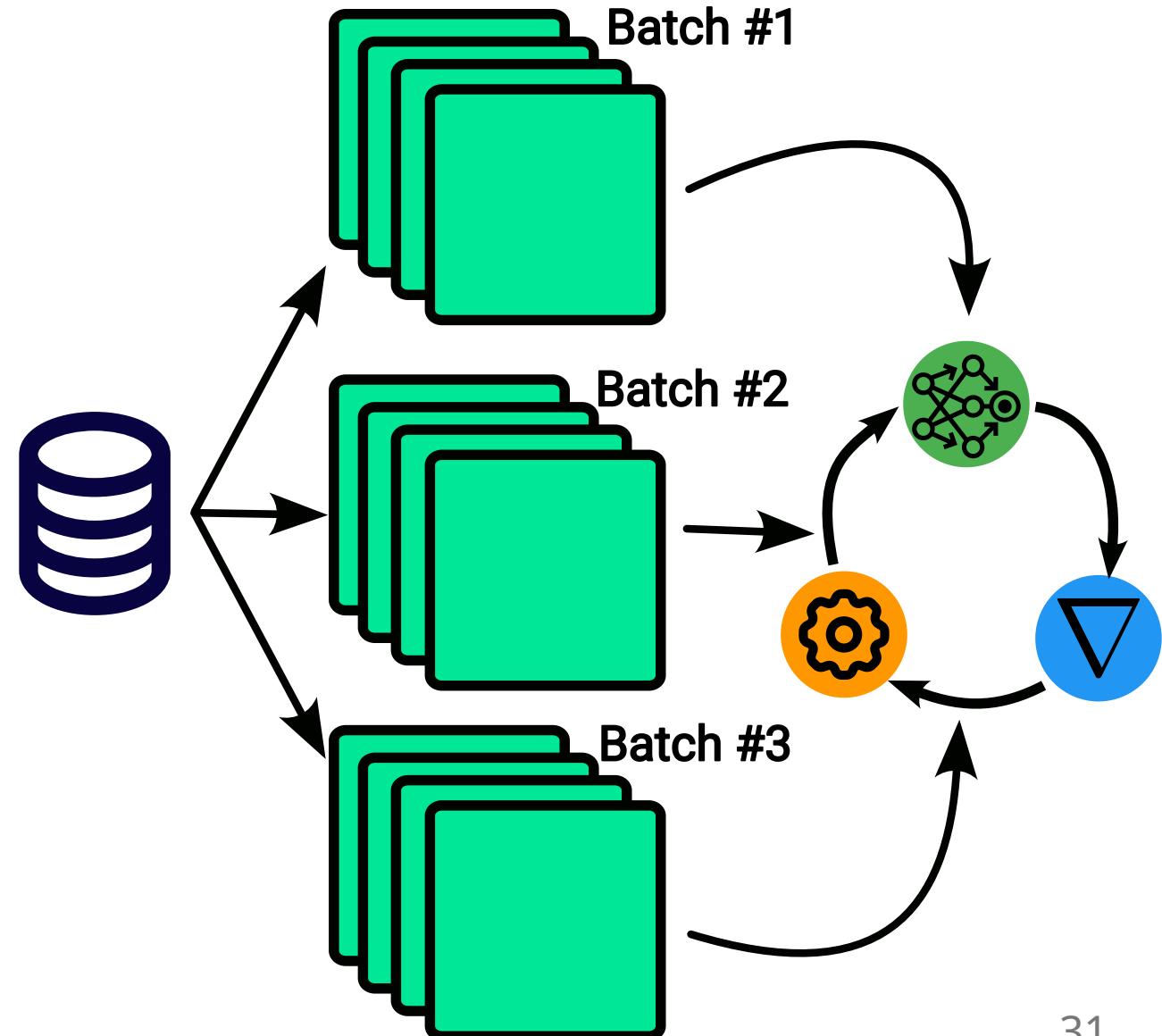
# Neural Network – Backpropagation



# Epoch

## Key Concepts

1. **Epochs**: Number of complete passes through the training dataset
2. **Batch Size** : Number of samples processed before updating the model
3. **Learning Rate** : Controls how much to change the model in response to the estimated error



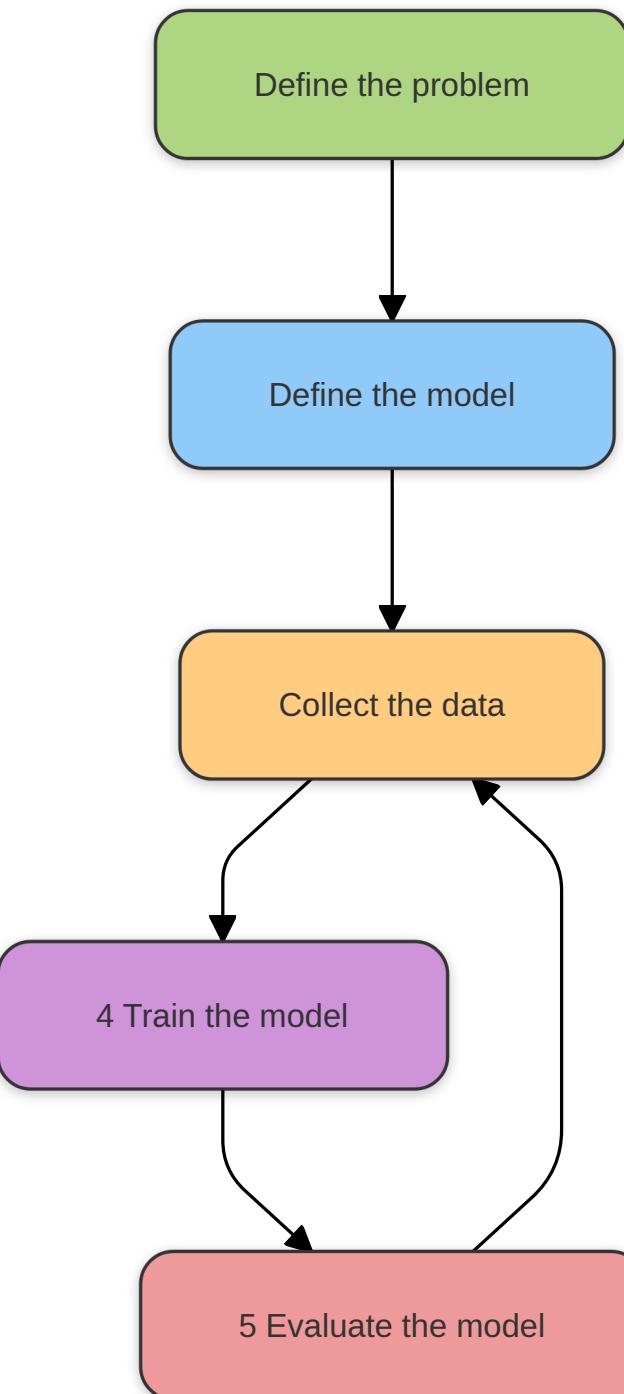
# Summary

- Deep learning requires a **model** and (lot of) **data**
- Deep Learning relies on a combination of **loss functions** , **optimizers** , **backpropagation** , and key parameters to learn effectively.

# Deep Learning

Steps to learn a model

1. Define the problem
  2. Define the model
  3. Collect the data
  4. Train the model
  5. Evaluate the model
- ... and repeat



# **Define the problem**

## **What are we trying to solve ?**

The problem can generally be defined by specifying the input and the output

## **Collect the data**

**What data do we have? Need of labels ?**

A machine learning model needs data to learn

Finding (good) data will define the success of the model

# Preprocess the data

- Images are not always in the right format
- Some data augmentation can be useful
- Normalization
- Some data may be dirty (garbage in, garbage out)

# Define the model

## What architecture to use?

Depending on the specific task, some architectures may be more suited than others

Structure ? Recurrence ? Time Series ? Natural Language ?

# Code the model

- Define the architecture using a library
- Loss function : depending on the task
- Optimizer : SGD, Adam, ...
- Learning loop : classic code [see below](#)

Generally these steps rely on a library (PyTorch, TensorFlow, ...)

# Train the model

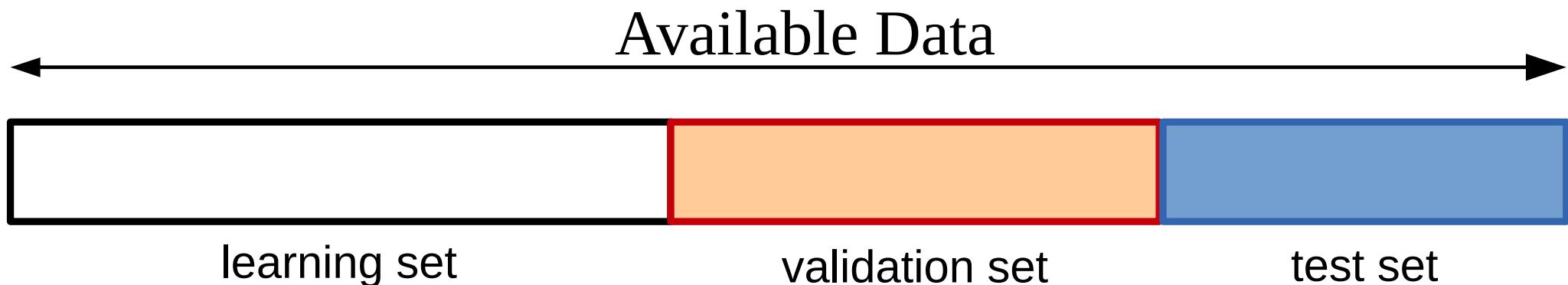
- Feed the data to the model
- Compute the loss
- Backpropagate the gradients
- Update the weights
- Repeat

This step may take a long time depending on the resources, architecture, and data

# Good Practices

## Train/valid/test split

We are interested in the generalization of the model: test it on unseen data to assess its performance. Tune hyperparameters on the validation set.



# Good Practices

## Always test a simple baseline

To asses the performance of a model, we need to compare it to a simple baseline. Even random guessing can be a good baseline.

## Learn on representative data

Modern IA is only as good as the data it was trained on. Make sure the data is representative of the task.

# Good Practices

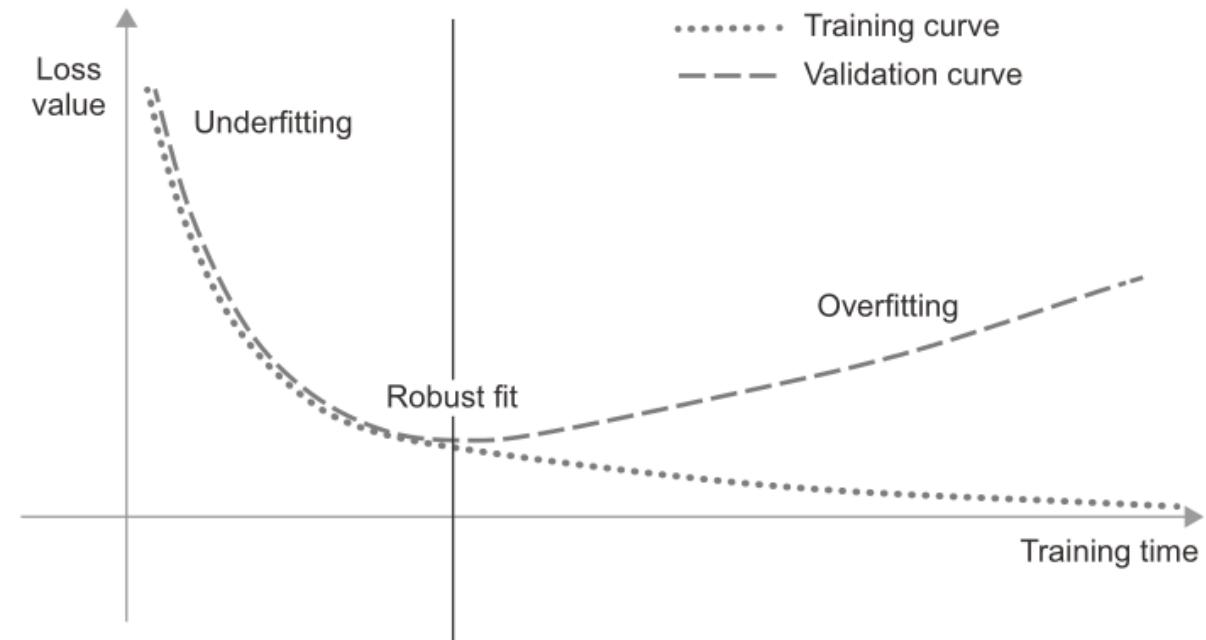
## Check learning curves

Training loss must decrease.

Validation loss must decrease, then increase.

Best model is the one with the lowest validation loss.

[figure taken from F. Chollet]



# Let's code

We will use PyTorch to train a simple CNN on MNIST

```
import torch
import torchvision
import torch.nn as nn
import torch.optim as optim
import torch.nn.functional as F

train_loader = torch.utils.data.DataLoader(torchvision.datasets.MNIST('data', train=True, download=True, transform=torchvision.transforms.ToTensor()), batch_size=32, shuffle=True)

class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(1, 32, 3, 1)
        self.conv2 = nn.Conv2d(32, 64, 3, 1)
        self.dropout1 = nn.Dropout(0.25)
        self.dropout2 = nn.Dropout(0.5)
        self.fc1 = nn.Linear(9216, 128)
        self.fc2 = nn.Linear(128, 10)

    def forward(self, x):
        x = F.relu(self.conv1(x))
        x = F.relu(self.conv2(x))
        x = F.max_pool2d(x, 2)
        x = self.dropout1(x)
        x = torch.flatten(x, 1)
        x = F.relu(self.fc1(x))
        x = self.dropout2(x)
        x = self.fc2(x)
        return x

model = Net()

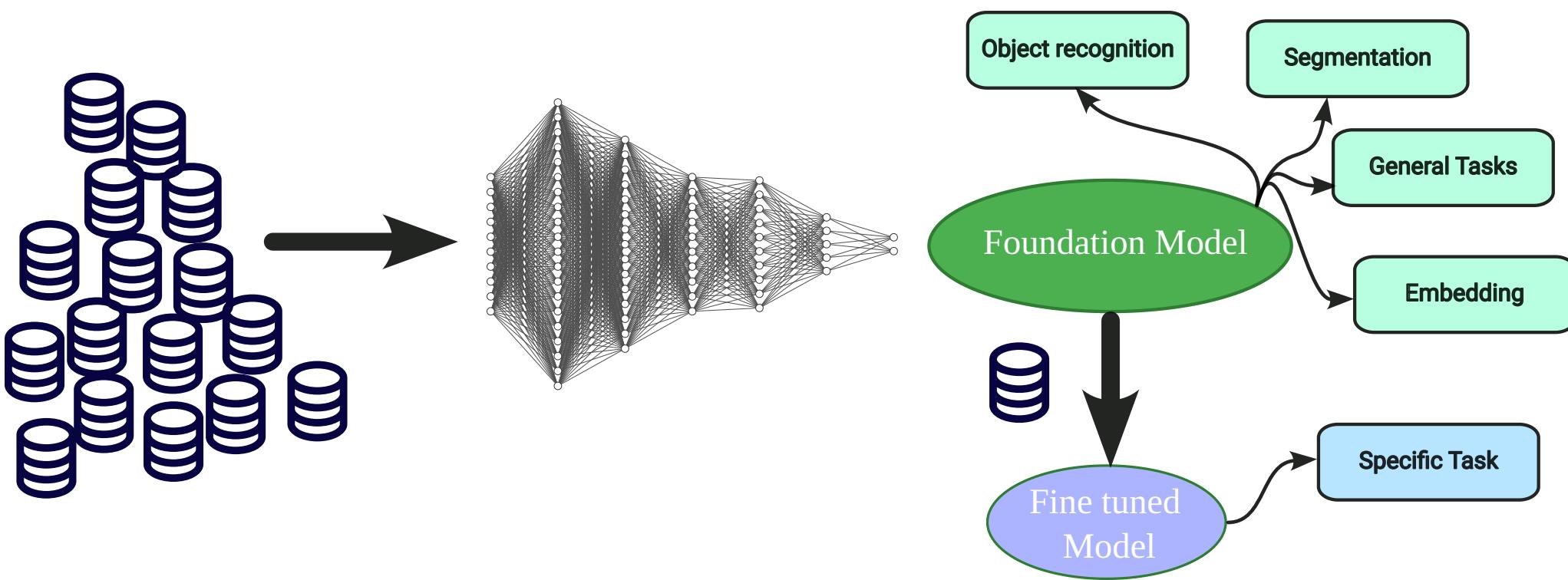
# Define the loss and the optimizer
criterion = nn.CrossEntropyLoss()
optimizer = optim.Adam(model.parameters(), lr=0.001)
# Train the model
nb_batch_to_print = 100
for epoch in range(10): # loop over the dataset multiple times
    running_loss = 0.0
    for i, data in enumerate(train_loader, 0):
        inputs, labels = data
        optimizer.zero_grad()
        outputs = model(inputs)
        loss = criterion(outputs, labels)
        loss.backward()
        optimizer.step()
        running_loss += loss.item()
        if i % nb_batch_to_print == nb_batch_to_print-1:
            print('[%d, %5d] loss: %.3f' %
                  (epoch + 1, i + 1, running_loss / nb_batch_to_print))
            running_loss = 0.0

print('Finished Training')
```

# Foundation Model

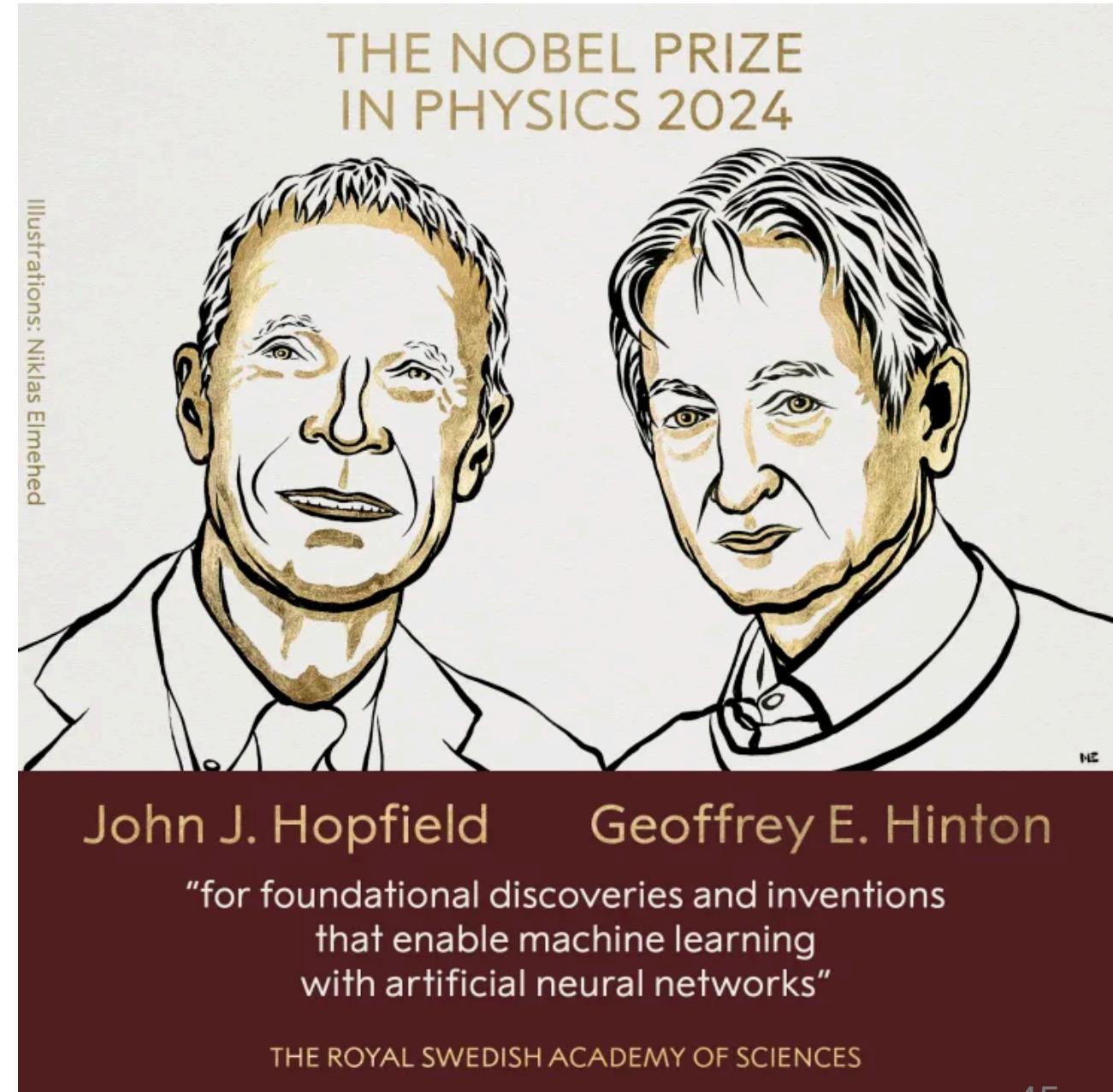
large AI model trained on vast amounts of data, capable of performing a wide range of tasks.

- Examples : GPT-3, BERT, DALL-E, Llama, [SAM](#), ...

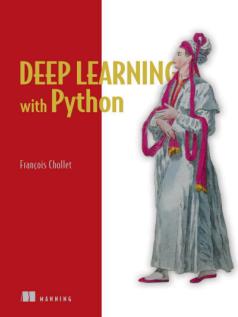
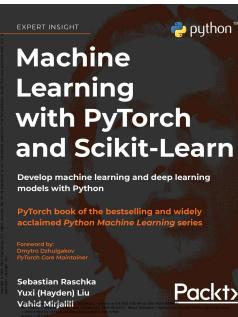


# Conclusion

- Deep Learning is a powerful tool for Computer Vision
- Many resources are freely available
- Learning a model is not theoretically complex
- Complexity is on the engineering side
- Let's get a Nobel !



# References - Going further

-  Deep Learning with Python
-  Machine Learning with PyTorch and Scikit-Learn
- Yann Le Cun au collège de france