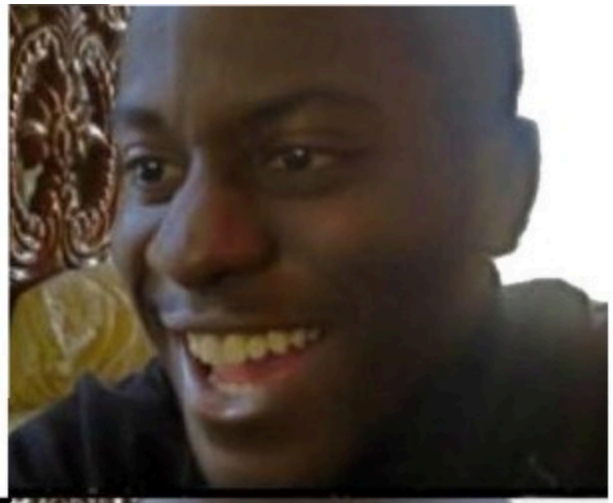
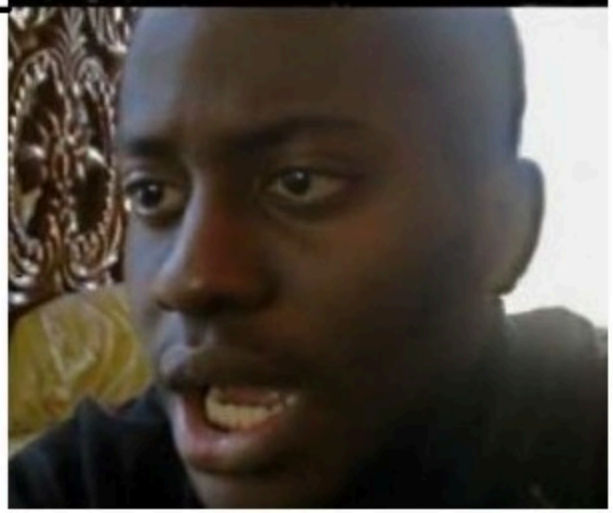
# Neural Networks

For a great supplement, read this article about how ChatGPT works (it's only 100 pages... 😉)

When professor says we are making neural nets



When he starts explaining them



# Why?

Neural networks are **advanced** machine learning models designed to replicate many observed characteristics of human brains

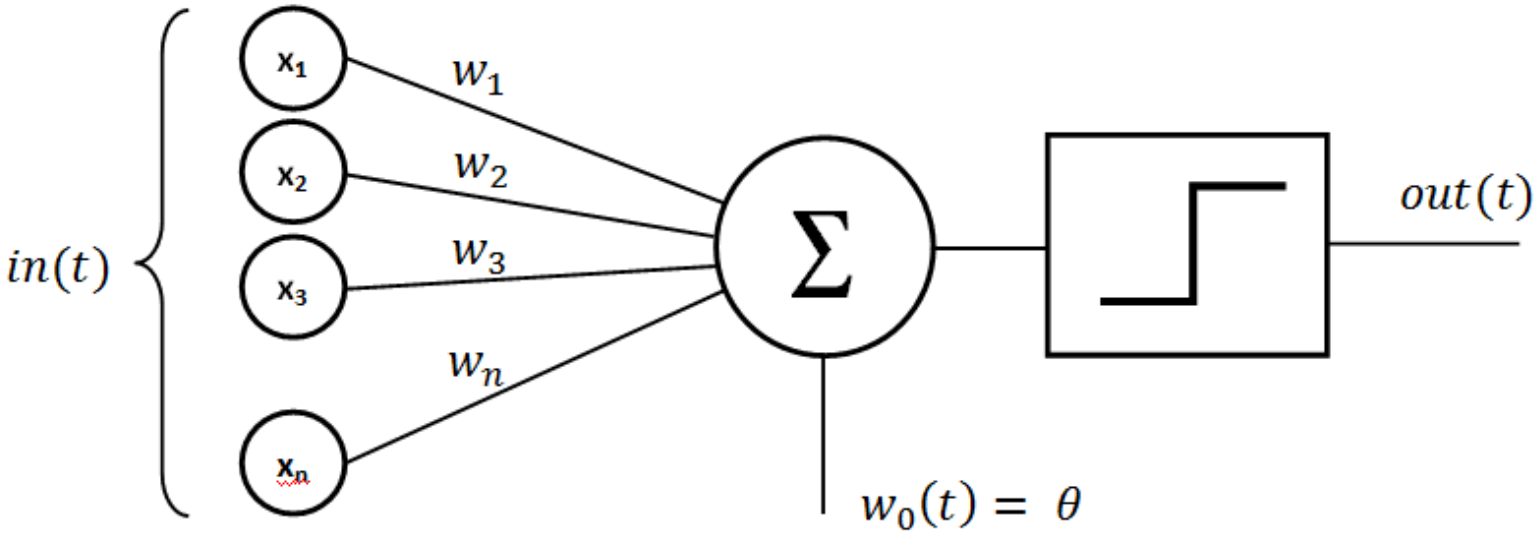
- Hard to use well
- Difficult to explain clearly
- Highly valuable **in specific contexts**

# The basics - Perceptrons

A perceptron is the computational equivalent of a single neuron

Let's describe it with a visual

# A perceptron



# What is an Activation Function?

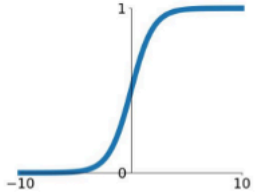
An activation function is a math function that determines when a perceptron moves from "off" to "on".

Again, let's describe this visually

# Activation Functions

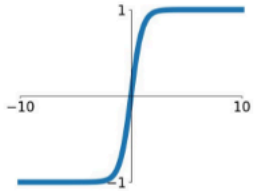
**Sigmoid**

$$\sigma(x) = \frac{1}{1+e^{-x}}$$



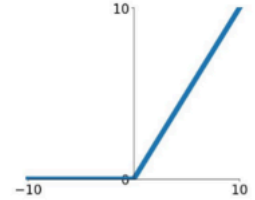

**tanh**

$$\tanh(x)$$



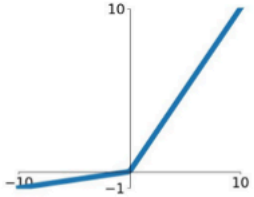

**ReLU**

$$\max(0, x)$$




**Leaky ReLU**

$$\max(0.1x, x)$$

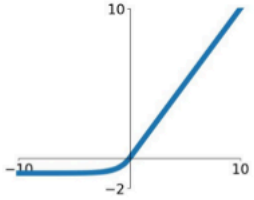



**Maxout**

$$\max(w_1^T x + b_1, w_2^T x + b_2)$$

**ELU**

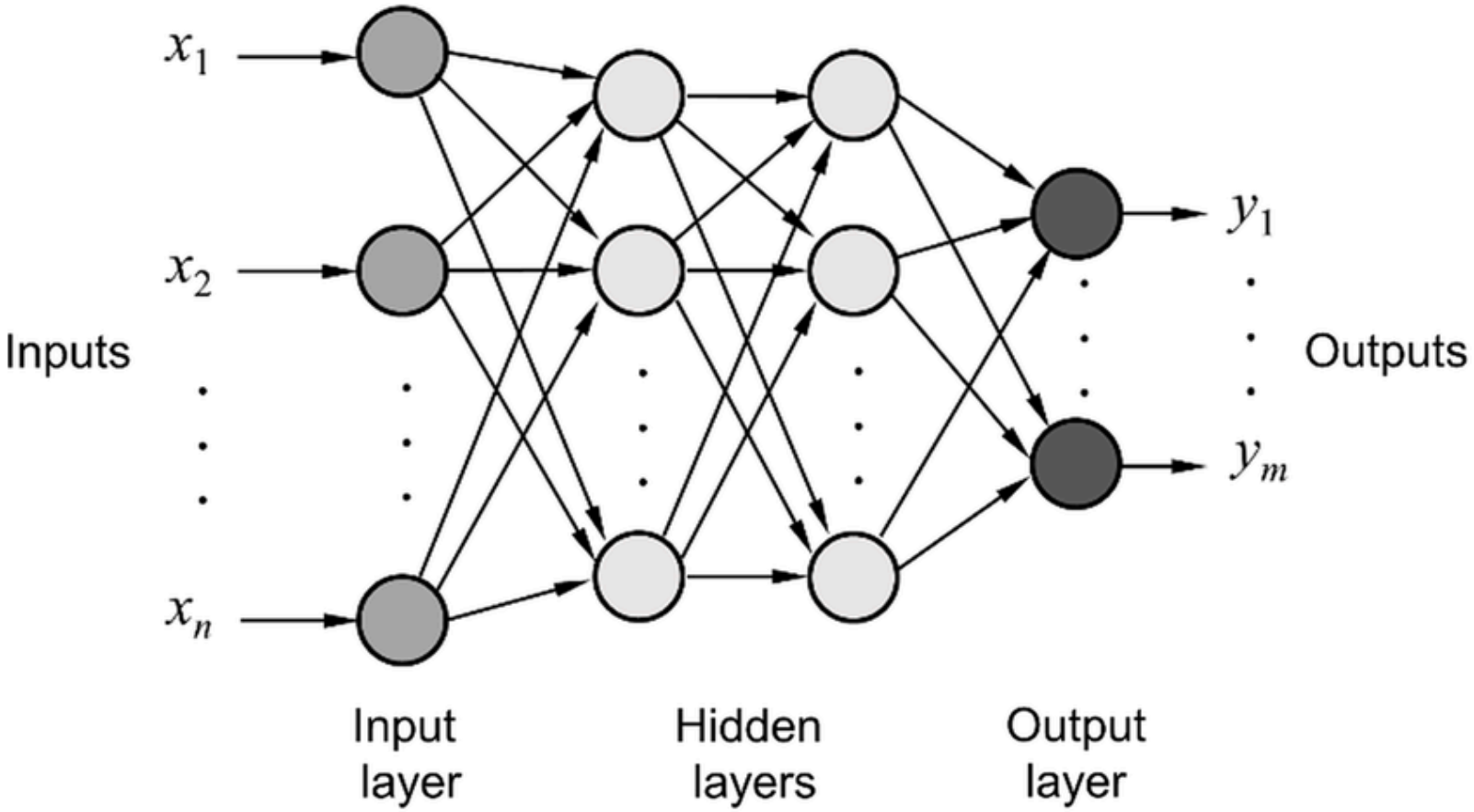
$$\begin{cases} x & x \geq 0 \\ \alpha(e^x - 1) & x < 0 \end{cases}$$



# How does this make a Neural Network?

Neural networks are made up of **layers** of perceptrons that are interconnected, leading from the **input layer** to the **output layer**.

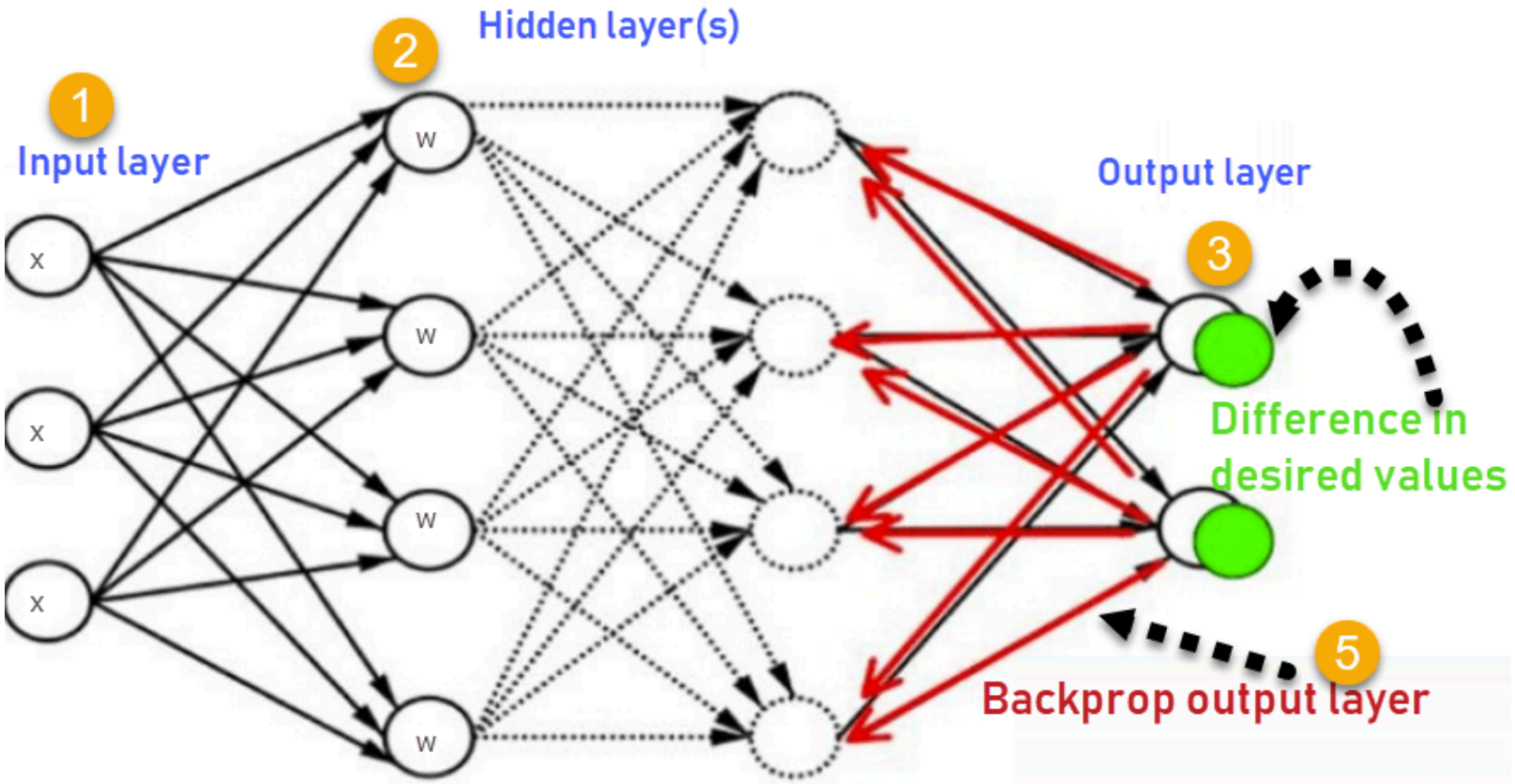
Any layer in between is called a **hidden layer**. Neural networks are often referred to as **deep learning** because of these hidden layers making the nerual network "deep".


$x_1$
$x_2$
Inputs
$x_n$
$y_1$
$y_m$
Outputs
Input layer
Hidden layers
Output layer

# How do we use them?

Our goal with a neural network is to train our network with **weights** and **biases** (these are what trigger the activation functions, remember?) so that the network is able to represent the complex process of predicting our outcome of interest.

# How we learn - Backpropagation



# How we learn - Backpropagation

Through inputs and backpropagation, we train our model to perform as well as we can on our task.

How do we choose the right network?

# Choosing the right network

1. Use one that someone else designed for the same (or similar) tasks
2. Evolutionary algorithms ("neuroevolution")
    - Here's an example: https://www.youtube.com/watch?v=qv6UVOQ0F44
3. Trial and error (probably not efficient)

# Using Keras to work with Neural Networks

This simple example comes from the keras documentation

```
import os
import numpy as np

os.environ["KERAS_BACKEND"] = "torch"

# Note that keras_core should only be imported after the backend
# has been configured. The backend cannot be changed once the
# package is imported.
import keras_core as keras
from keras_core import layers
```

# Prep and Load Data

```
# Model / data parameters
num_classes = 10
input_shape = (28, 28, 1)

# Load the data and split it between train and test sets
(x_train, y_train), (x_test, y_test) = keras.datasets.mnist.load_data()
```

It's better for this example to pull MNIST from the library, since it is already stored on Google's server so it loads the FULL 60,000 observations very quickly

# Scale Image Data

```
# Scale images to the [0, 1] range
x_train = x_train.astype("float32") / 255
x_test = x_test.astype("float32") / 255
```

Many small images come with data stored in levels from 0 to 255 (8-bits), and we need to scale that to be between 0 and 1

# Color channels

```
# Make sure images have shape (28, 28, 1)
print("x_train shape before transform:", x_train.shape)
x_train = np.expand_dims(x_train, -1)
x_test = np.expand_dims(x_test, -1)
print("x_train shape after transform:", x_train.shape)
print(x_train.shape[0], "train samples")
print(x_test.shape[0], "test samples")
```

Many images have 3 color channels, so our data needs to have three dimensions (height, width, color channels). Since this data is black and white, we only have one channel.

# Convert dependent variable

```
# convert class vectors to binary class matrices – one hot encoding
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)
```

Instead of 1 column with values between 0 and 9, we need 10 columns, with ones and zeros, called **one hot encoding**, just like what we did for regressions with categorical data.

# Specify the model

```
model = keras.Sequential(
    [
        keras.Input(shape=input_shape),
        layers.Conv2D(32, kernel_size=(3, 3), activation="relu"),
        layers.MaxPooling2D(pool_size=(2, 2)),
        layers.Conv2D(64, kernel_size=(3, 3), activation="relu"),
        layers.MaxPooling2D(pool_size=(2, 2)),
        layers.Flatten(),
        layers.Dropout(0.5),
        layers.Dense(num_classes, activation="softmax"),
    ]
)

model.summary()
```

# Specify the model

**Model: "sequential"**

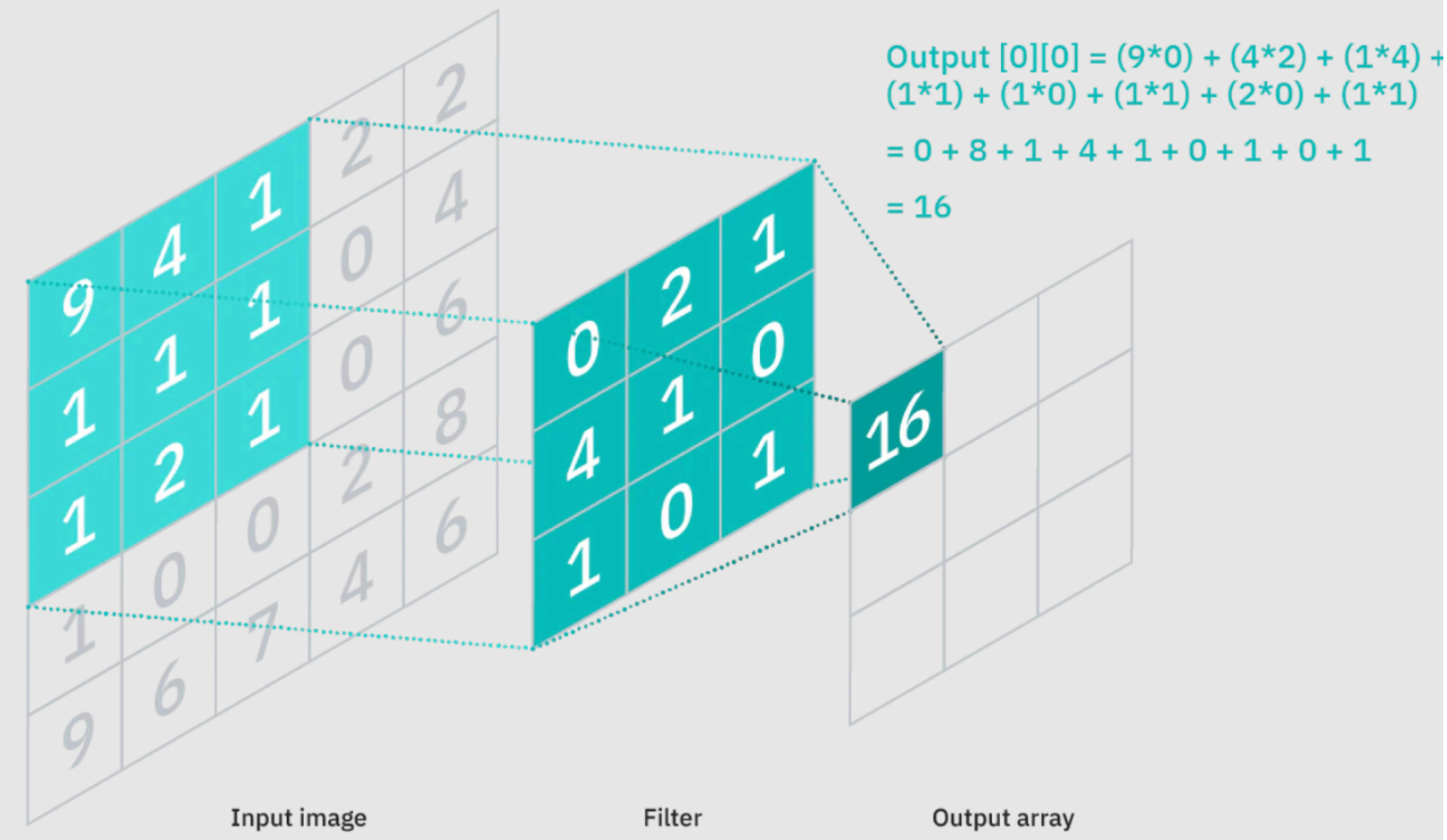
| Layer (type) | Output Shape | Param # |
|---|---|---|
| conv2d (Conv2D) | (None, 26, 26, 32) | 320 |
| max_pooling2d (MaxPooling2D) | (None, 13, 13, 32) | 0 |
| conv2d_1 (Conv2D) | (None, 11, 11, 64) | 18,496 |
| max_pooling2d_1 (MaxPooling2D) | (None, 5, 5, 64) | 0 |
| flatten (Flatten) | (None, 1600) | 0 |
| dropout (Dropout) | (None, 1600) | 0 |
| dense (Dense) | (None, 10) | 16,010 |

**Total params:** 34,826 (136.04 KB)
**Trainable params:** 34,826 (136.04 KB)
**Non-trainable params:** 0 (0.00 B)

This model is ~10,000,000 times smaller than ChatGPT!

# What do all these "layers" mean??

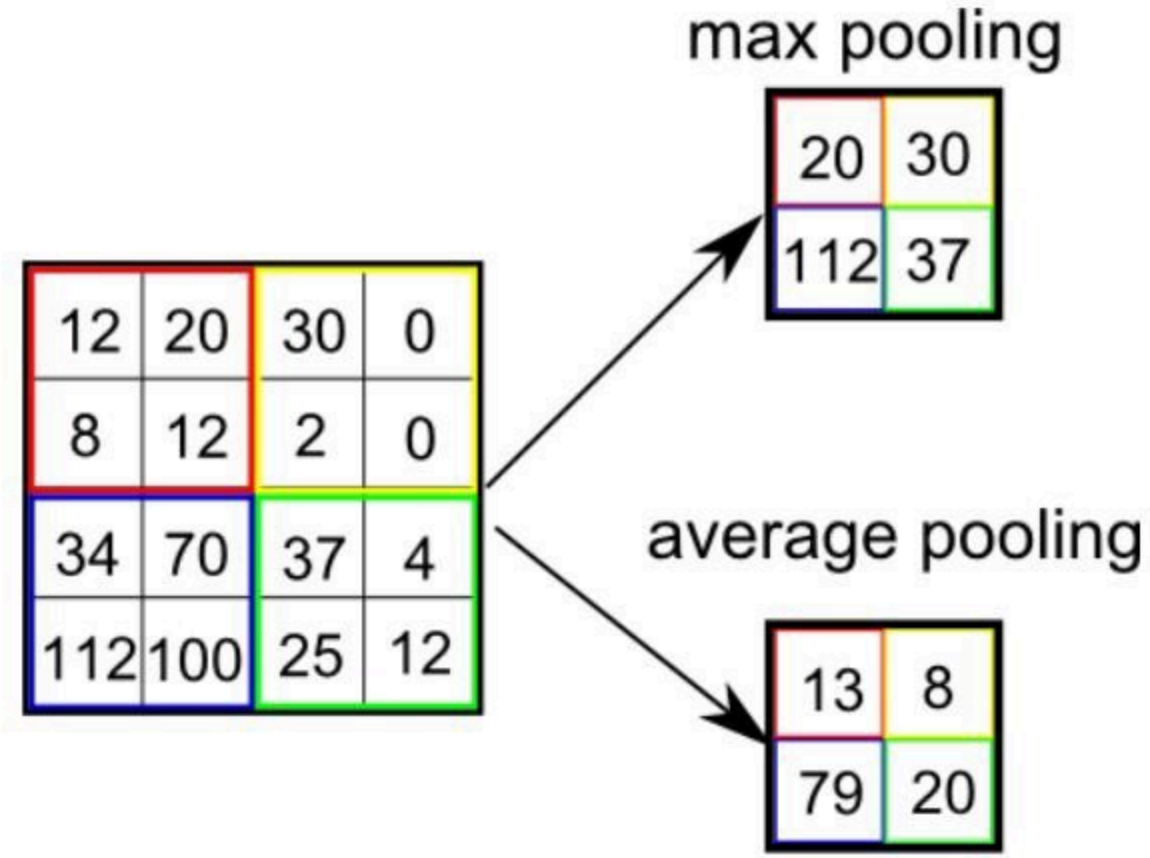
# Convolution



# Convolution

The goal of convolution is to try to extract patterns in our image through small-scale filters applied to each region of the image. This reduces the size of the image, but the result is a matrix of "pattern" data.

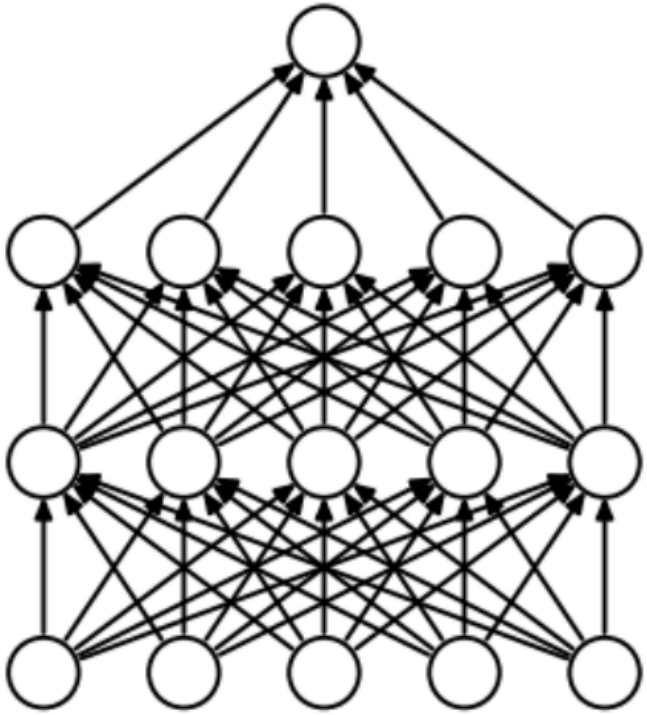
# Pooling


max pooling
20 30
112 37
12 20 30 0
8 12 2 0
34 70 37 4
112 100 25 12
average pooling
13 8
79 20

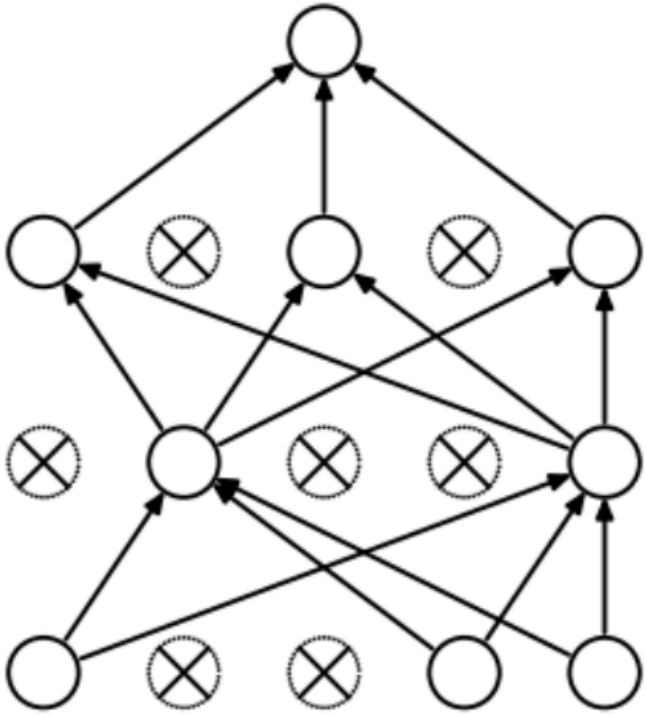
# Pooling

Pooling is a simple compression of the data, with our options being to average the value of a group of pixels, or to take the maximum value of the grouped pixels

# Dropout



(a) Standard Neural Net



(b) After applying dropout.

# Dropout

In a neural network, it is common for each neuron in one layer to connect to **every neuron in the next layer**. This is called a **fully connected** layer. In order to avoid overfitting, dropout "unplugs" a random percentage of neuron connections. The dropped connections are chosen randomly.

# Train the model

```
batch_size = 128
epochs = 3

# USING ENTROPY TO TRAIN OUR MODEL!
model.compile(loss="categorical_crossentropy",
    optimizer="adam", metrics=["accuracy"])

model.fit(x_train, y_train,
    batch_size=batch_size, epochs=epochs,
    validation_split=0.1)
```

# More definitions

**Batch size**: The number of image samples provided at once to our model. We have to keep this relatively small, since it takes a lot of computer memory to train the models on a set of images.

**Epochs**: The number of times we will loop over the **entire data set** as we train our model. More epochs leads to more refined models, but also takes a long time.

# Score the model

```
score = model.evaluate(x_test, y_test, verbose=0)
print("Test loss:", score[0])
print("Test accuracy:", score[1])
```

Does this model outperform our decision trees and random forests? Why?

# Lab Time!

Work on the project or experiment with the neural network we made. There is no required homework today! 😃

*(Nothing needs to be submitted for Assignment 11)*