Artificial Intelligence in Finance and Quantitative Analysis

# Deep Learning in Finance
# Reinforcement Learning in Finance

1111AIFQA09
MBA, IM, NTPU (M6132) (Fall 2022)
Tue 2, 3, 4 (9:10-12:00) (B8F40)

https://meet.google.com/paj-zhhj-mya


**Min-Yuh Day, Ph.D,**
**Associate Professor**

Institute of Information Management, National Taipei University

https://web.ntpu.edu.tw/~myday


2022-11-22

# Syllabus

| Week | Date | Subject/Topics |
|---|---|---|
| 1 | 2022/09/13 | Introduction to Artificial Intelligence in Finance and Quantitative Analysis |
| 2 | 2022/09/20 | AI in FinTech: Metaverse, Web3, DeFi, NFT, Financial Services Innovation and Applications |
| 3 | 2022/09/27 | Investing Psychology and Behavioral Finance |
| 4 | 2022/10/04 | Event Studies in Finance |
| 5 | 2022/10/11 | Case Study on AI in Finance and Quantitative Analysis I |
| 6 | 2022/10/18 | Finance Theory |

# Syllabus

| Week | Date | Subject/Topics |
| --- | --- | --- |
| 7 | 2022/10/25 | Data-Driven Finance |
| 8 | 2022/11/01 | Midterm Project Report |
| 9 | 2022/11/08 | Financial Econometrics and Machine Learning |
| 10 | 2022/11/15 | AI-First Finance |
| 11 | 2022/11/22 | Deep Learning in Finance;<br>Reinforcement Learning in Finance |
| 12 | 2022/11/29 | Case Study on AI in Finance and Quantitative Analysis II |

# Syllabus

| Week | Date | Subject/Topics |
| --- | --- | --- |
| 13 | 2022/12/06 | Industry Practices of AI in Finance and Quantitative Analysis |
| 14 | 2022/12/13 | Algorithmic Trading; Risk Management; Trading Bot and Event-Based Backtesting |
| 15 | 2022/12/20 | Final Project Report I |
| 16 | 2022/12/27 | Final Project Report II |
| 17 | 2023/01/03 | Self-learning |
| 18 | 2023/01/10 | Self-learning |

# Deep Learning in Finance

## Reinforcement Learning in Finance

# Outline

- Deep Learning (DL) in Finance
  - Dense Neural Networks (DNN)
  - Recurrent Neural Networks (RNN)
  - Convolutional Neural Networks (CNN)
- Reinforcement Learning (RL) in Finance
  - Q Learning (QL)
  - Improved Finance Environment
  - Improved Financial QL Agent

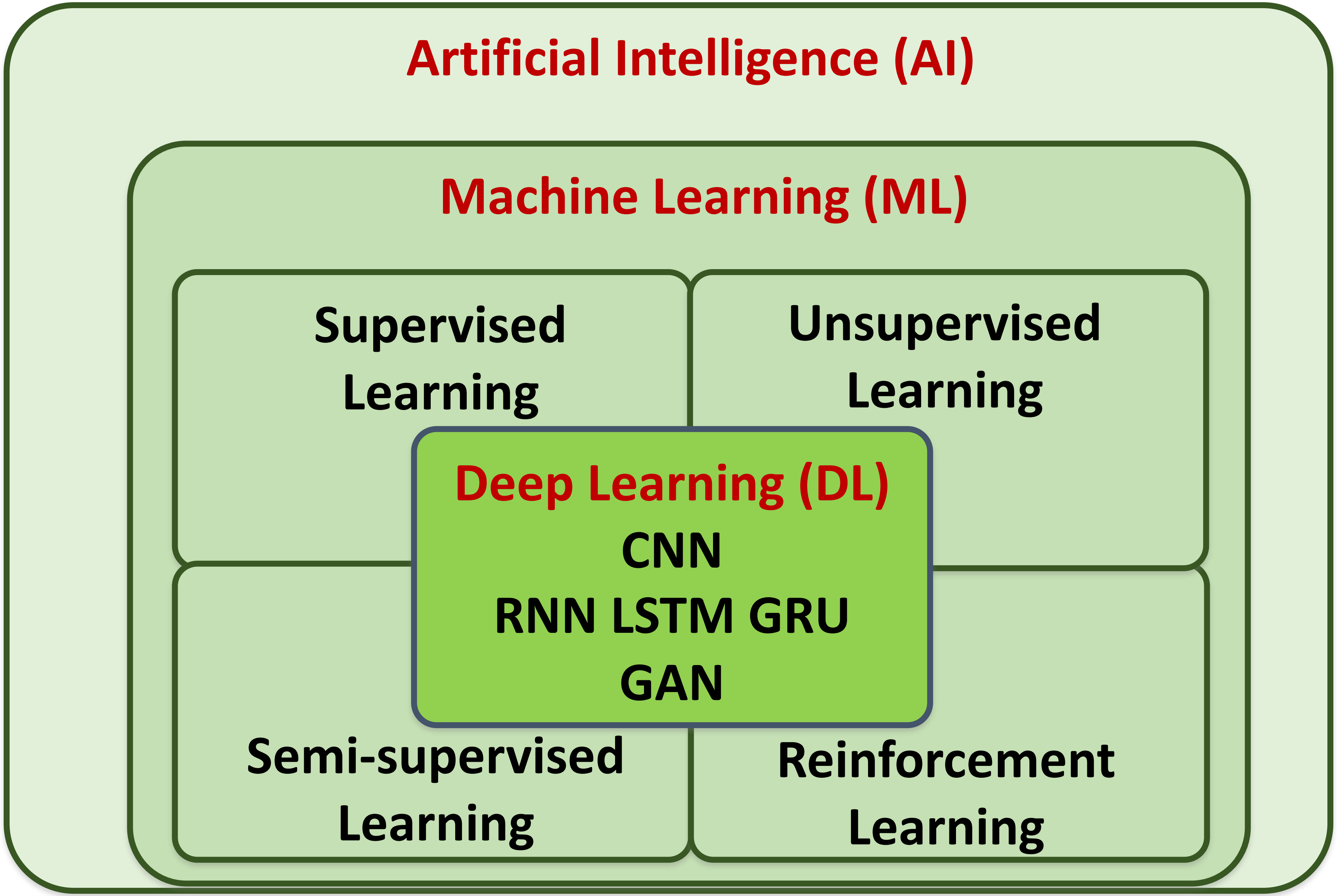
Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Deep Learning in Finance

- **Dense Neural Networks (DNN)**
- **Recurrent Neural Networks (RNN)**
- **Convolutional Neural Networks (CNN)**

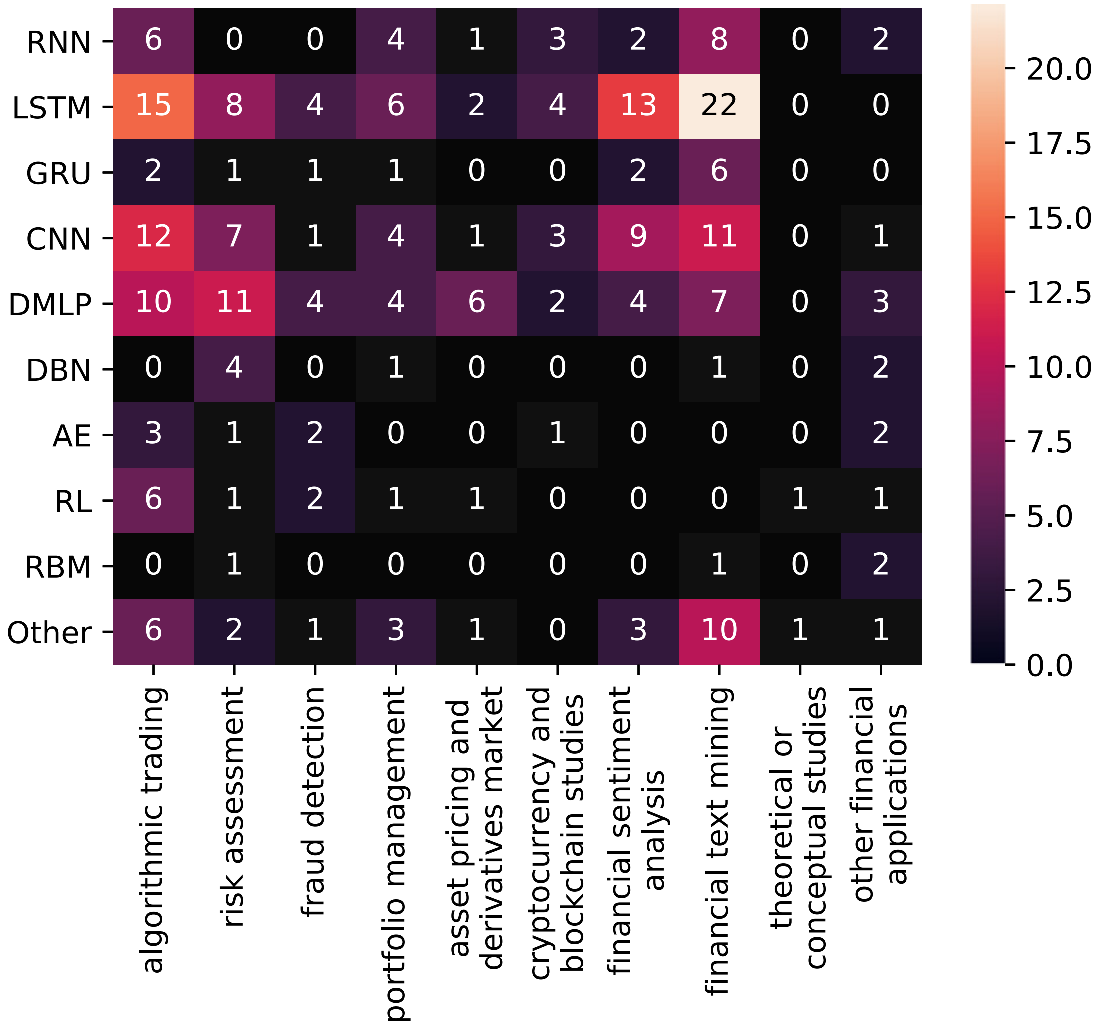
Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# AI, ML, DL



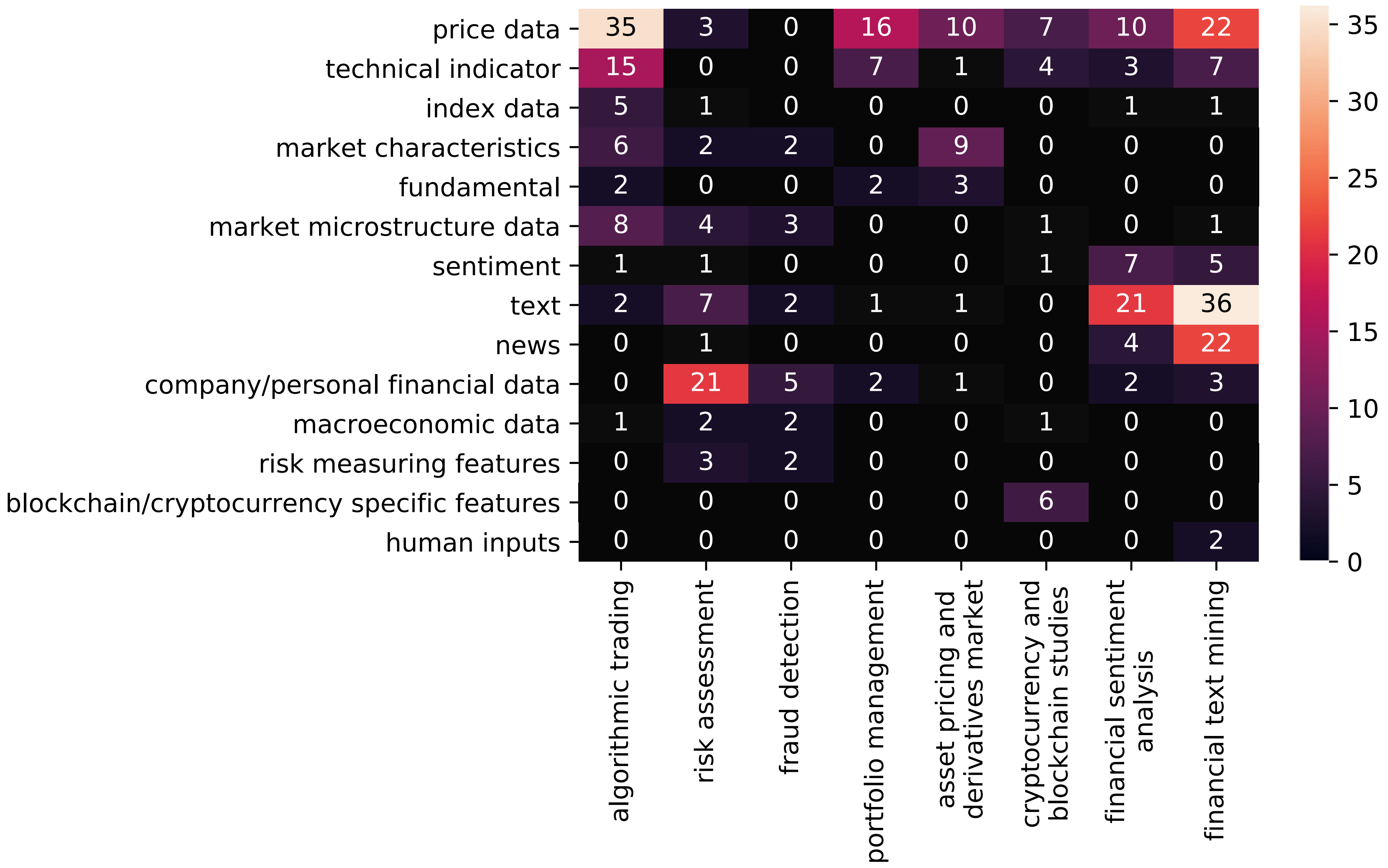

Source: https://leonardoaraujosantos.gitbooks.io/artificial-inteligence/content/deep_learning.html

# Deep learning for financial applications: Topic-Model Heatmap



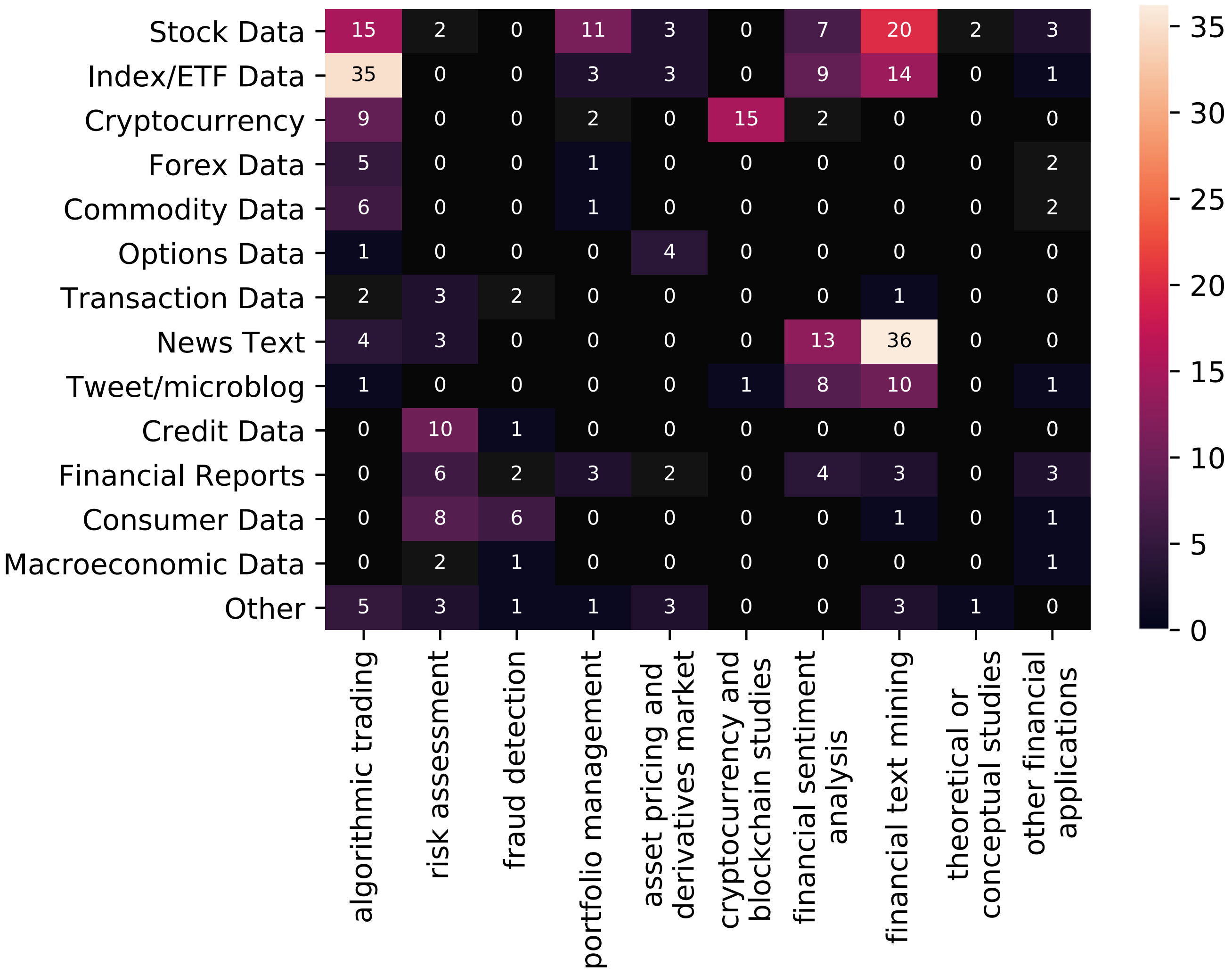

Source: Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey." Applied Soft Computing (2020): 106384.

# Deep learning for financial applications: Topic-Feature Heatmap



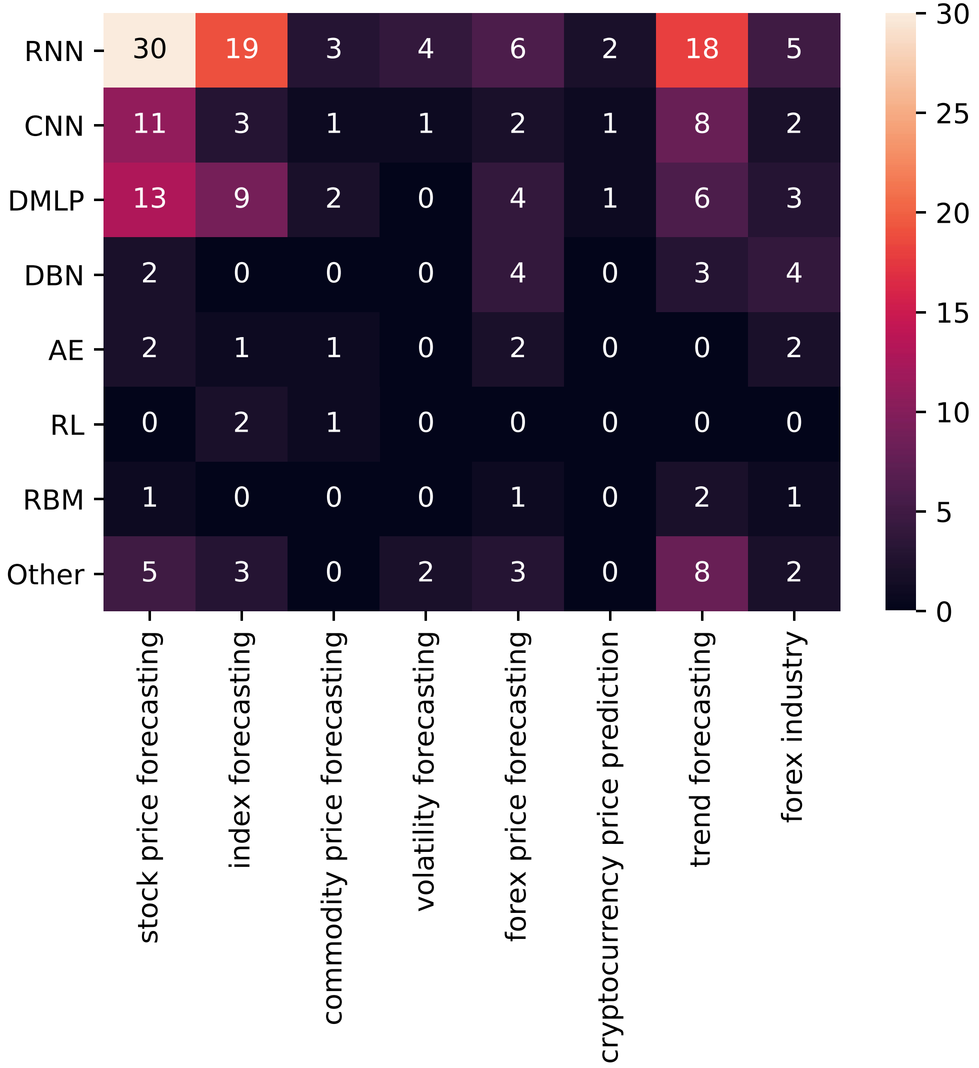

Source: Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey." Applied Soft Computing (2020): 106384.

# Deep learning for financial applications: Topic-Dataset Heatmap



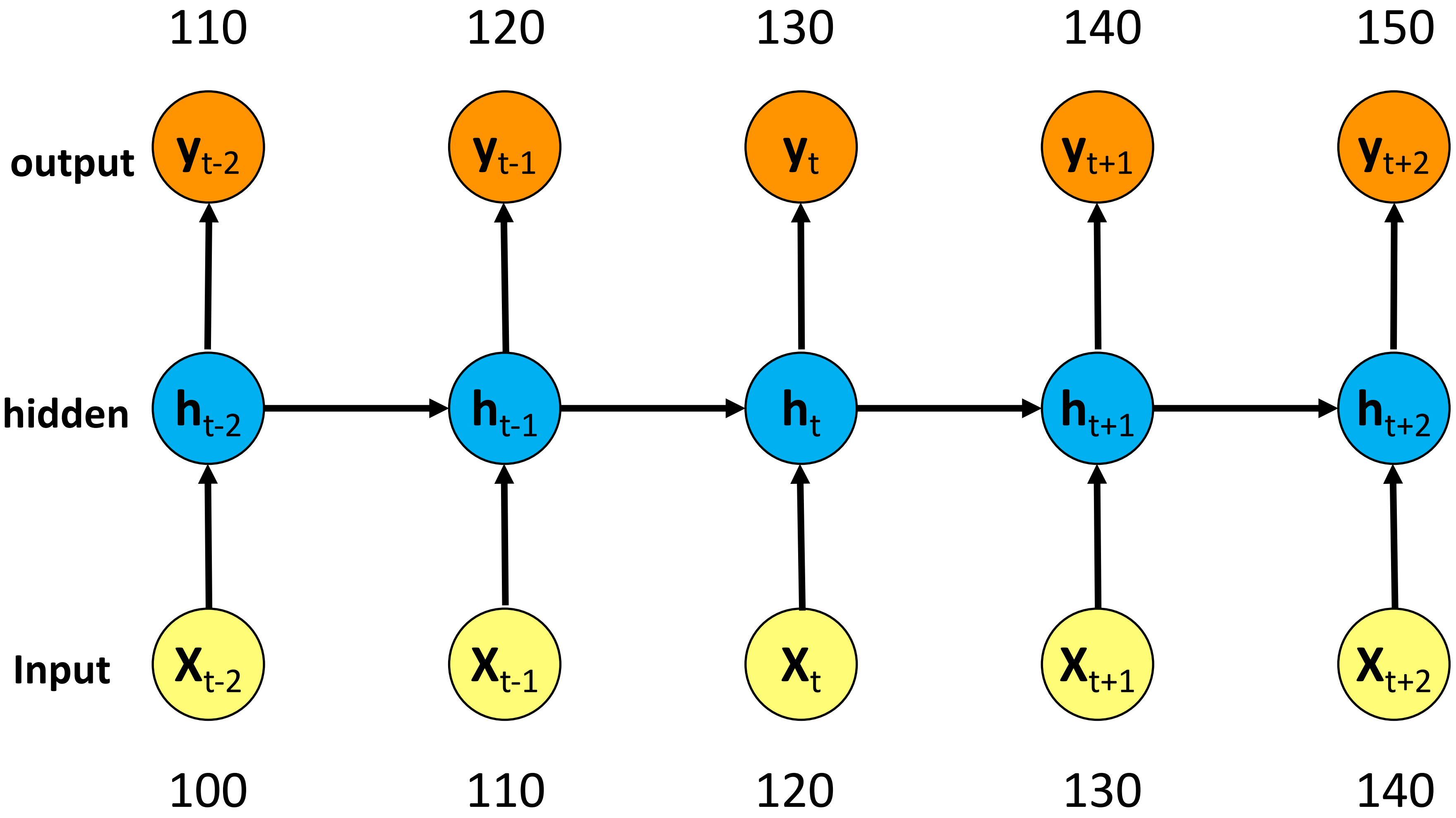

Source: Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey." Applied Soft Computing (2020): 106384.

# Financial time series forecasting with deep learning: Topic-model heatmap




Source: Omer Berat Sezer, Mehmet Ugur Gudelek, and Ahmet Murat Ozbayoglu (2020), "Financial time series forecasting with deep learning: A systematic literature review: 2005–2019." Applied Soft Computing 90 (2020): 106181.

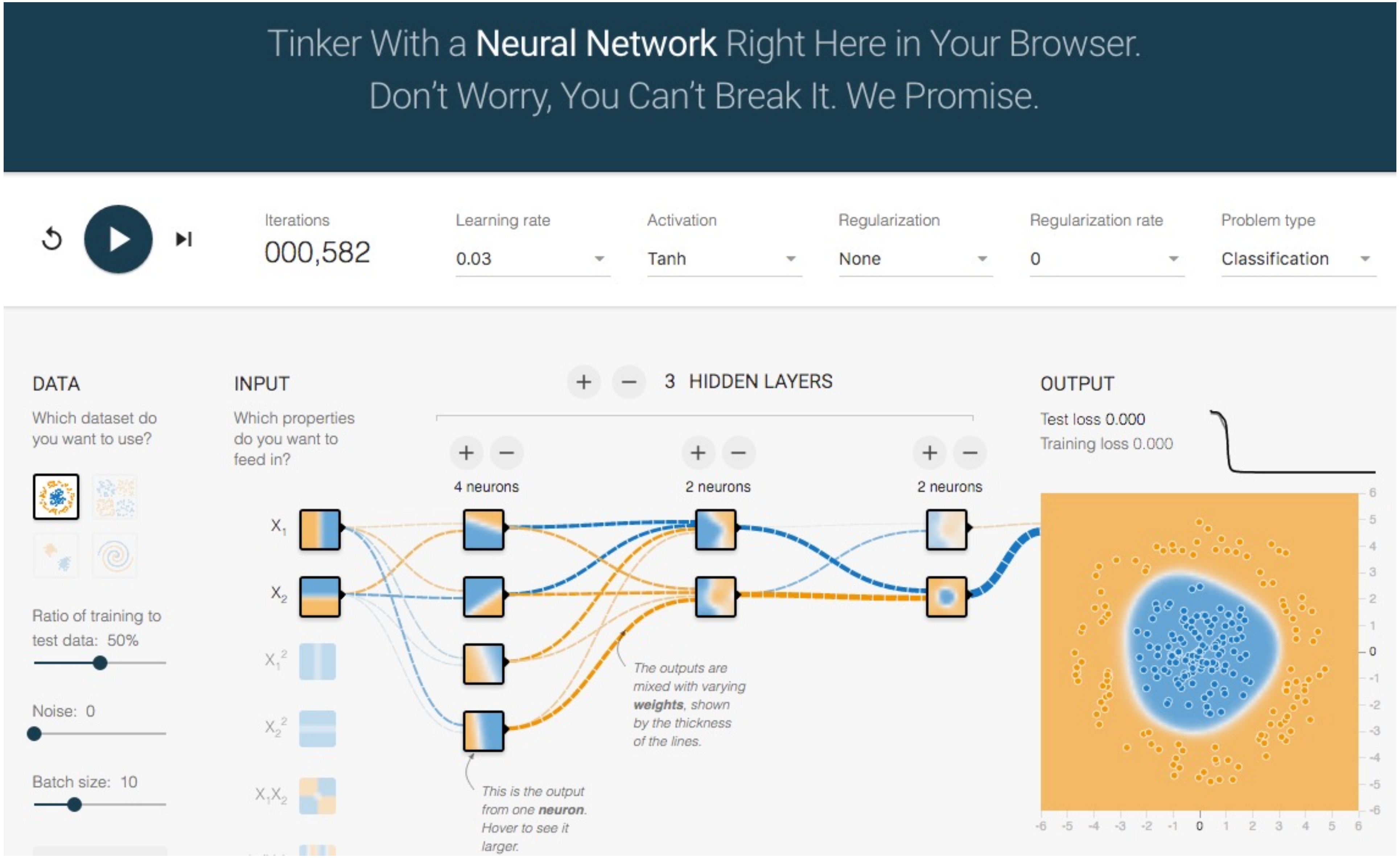
# Recurrent Neural Networks (RNN)
# Time Series Forecasting



# Deep Learning

# Deep Learning
# and
# Neural Networks

# TensorFlow Playground




http://playground.tensorflow.org/

# Tensor

- 3
    - # a rank 0 tensor; this is a scalar with shape []
- [1. ,2., 3.]
    - # a rank 1 tensor; this is a vector with shape [3]
- [[1., 2., 3.], [4., 5., 6.]]
    - # a rank 2 tensor; a matrix with shape [2, 3]
- [[[1., 2., 3.]], [[7., 8., 9.]]]
    - # a rank 3 tensor with shape [2, 1, 3]

https://www.tensorflow.org/

**Scalar** $80$

**Vector** $[50 \ \ 60 \ \ 70]$

**Matrix**
$$\begin{bmatrix} 50 & 60 & 70 \\ 55 & 65 & 75 \end{bmatrix}$$

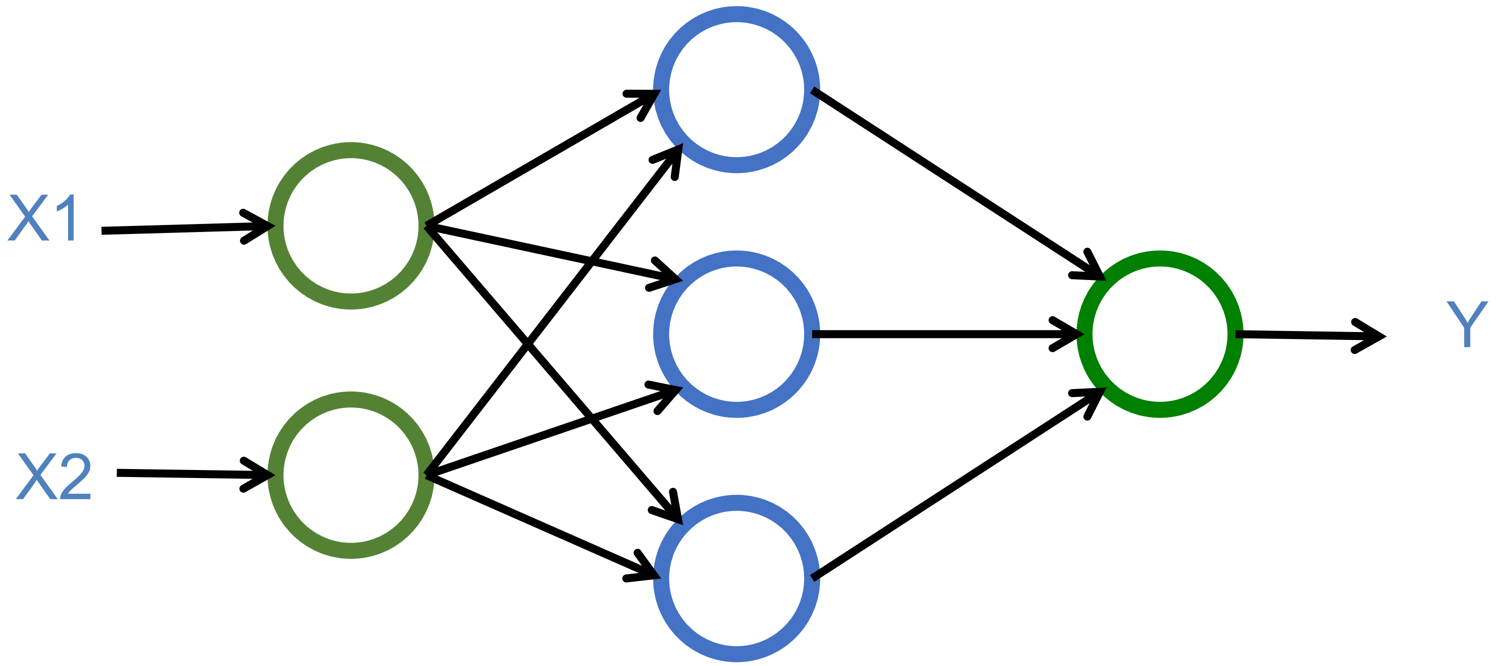
**Tensor**
$$\begin{bmatrix} [50 \ \ 60 \ \ 70] & [70 \ \ 80 \ \ 90] \\ [55 \ \ 65 \ \ 75] & [75 \ \ 85 \ \ 95] \end{bmatrix}$$

# Deep Learning
# and
# Neural Networks

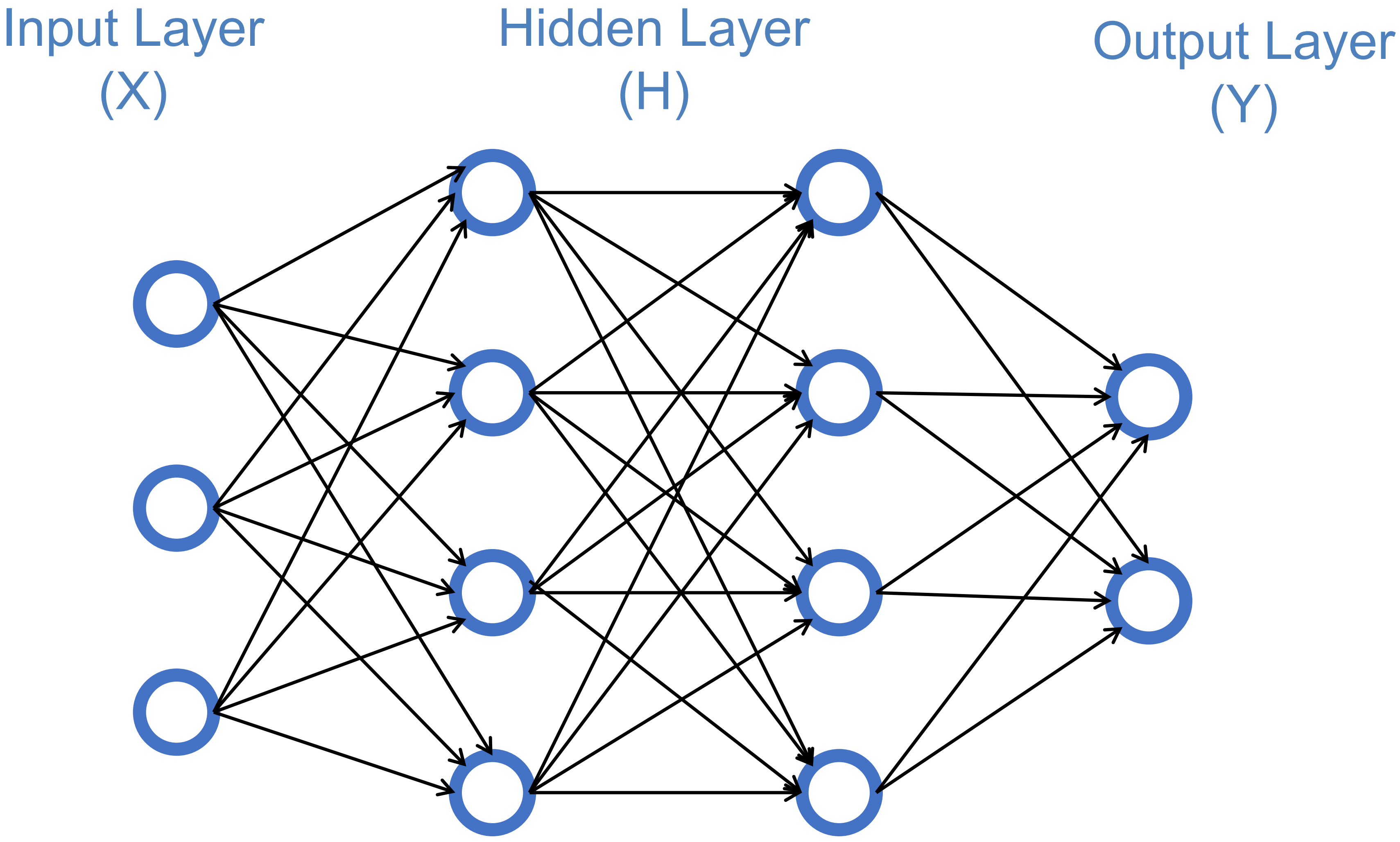
# Deep Learning Foundations: Neural Networks

# Deep Learning and Neural Networks

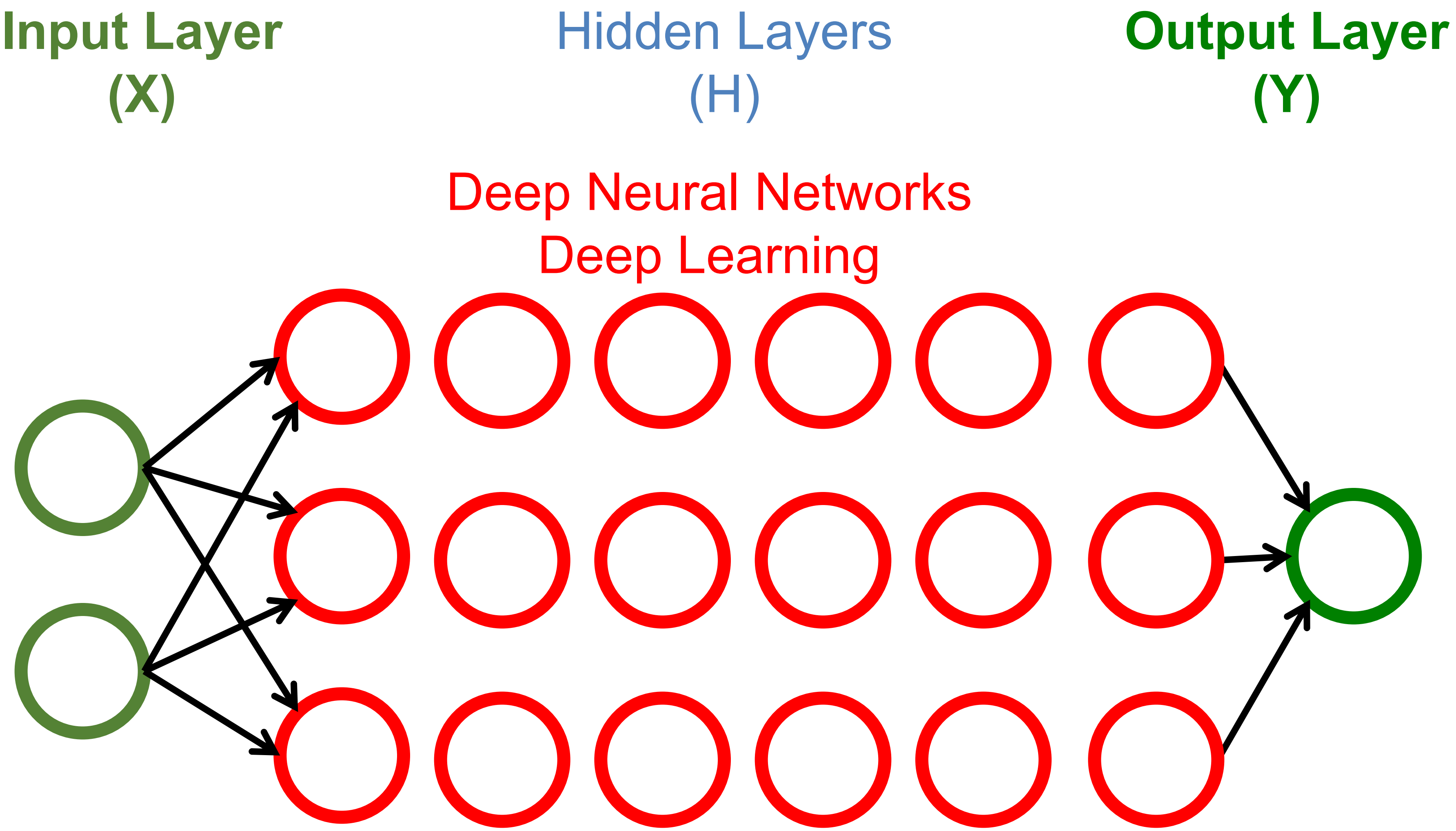
**Input Layer (X)** | Hidden Layer (H) | **Output Layer (Y)**



# Deep Learning and Neural Networks

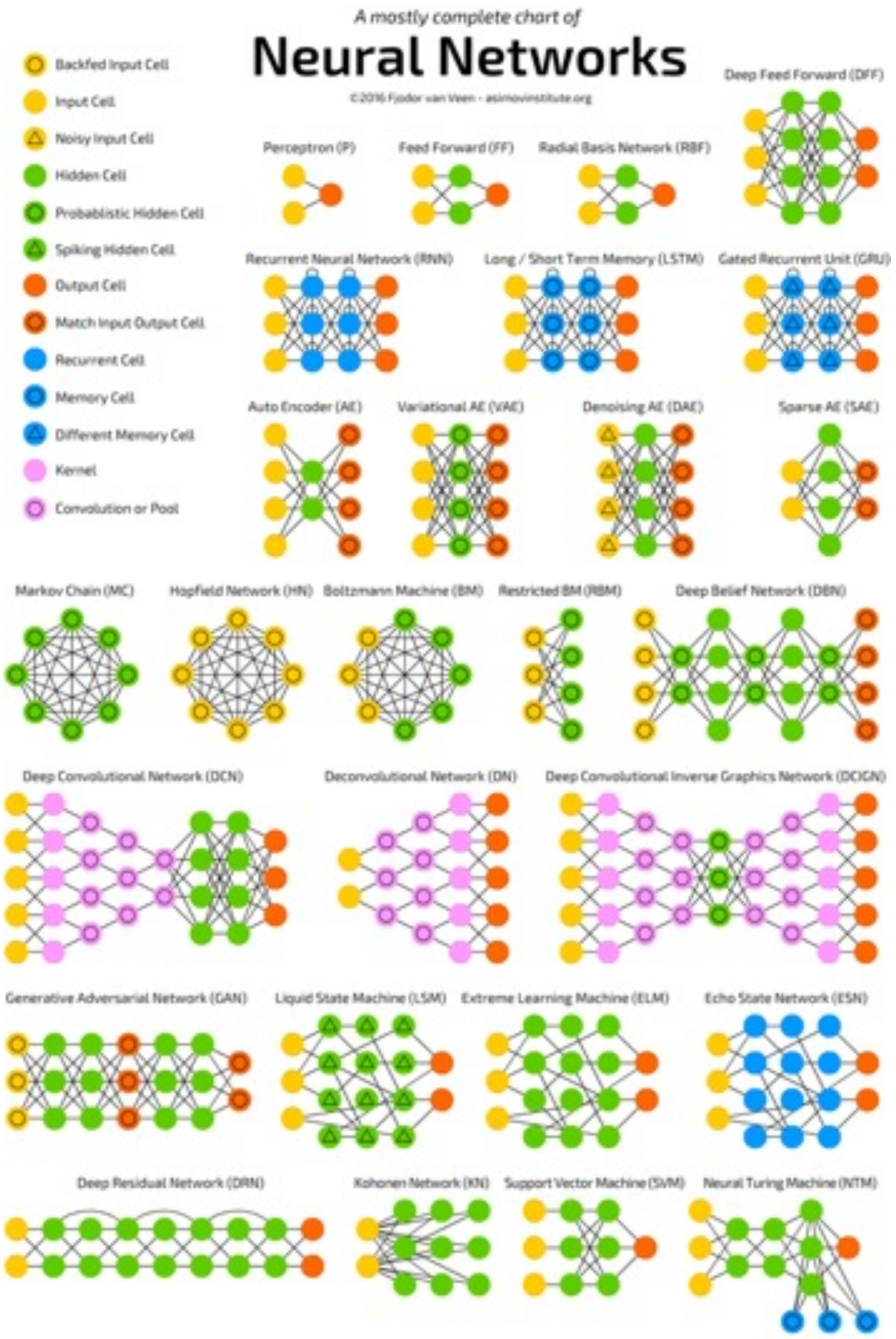


# Deep Learning and Neural Networks

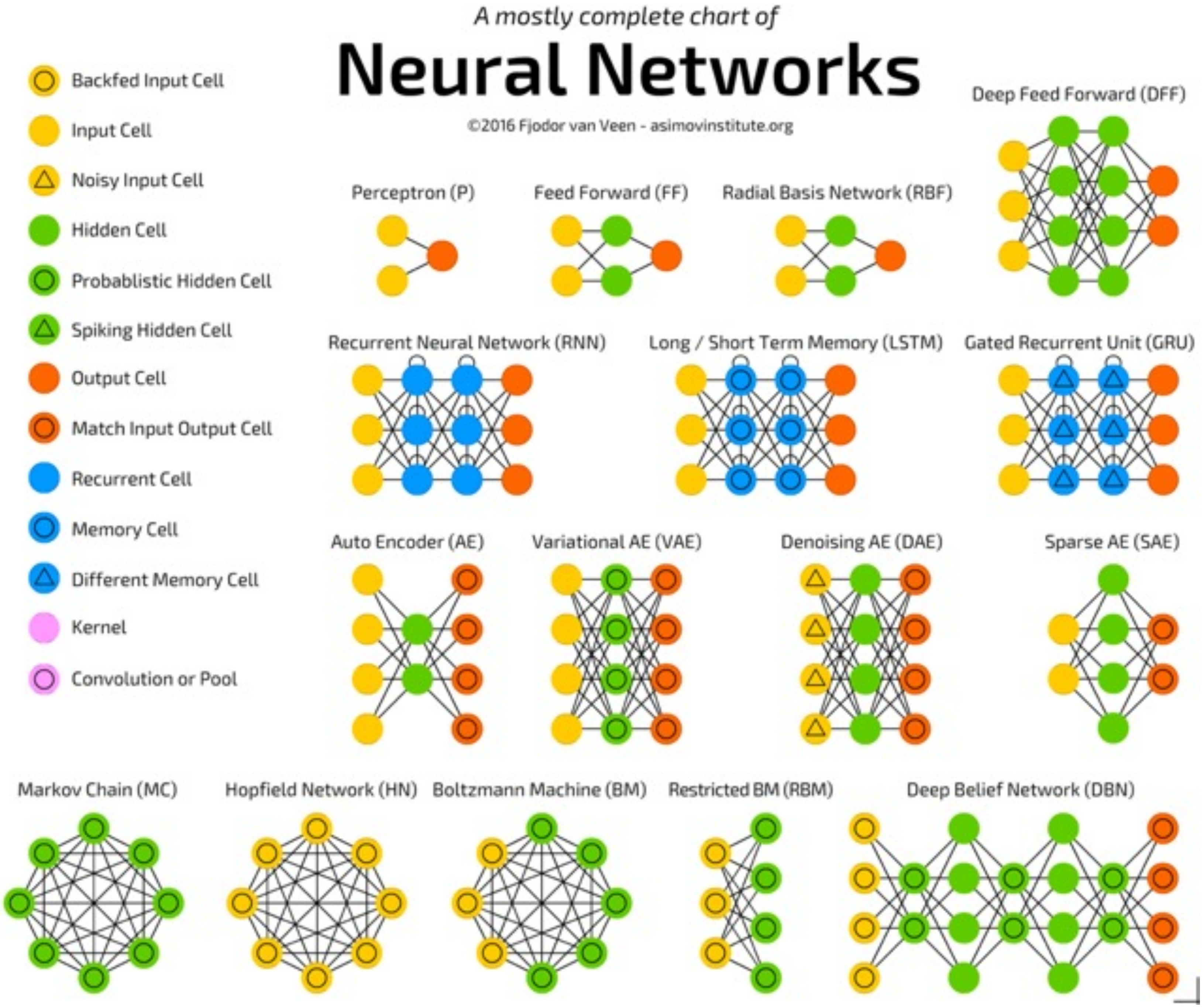


# Deep Learning
# and
# Deep Neural Networks

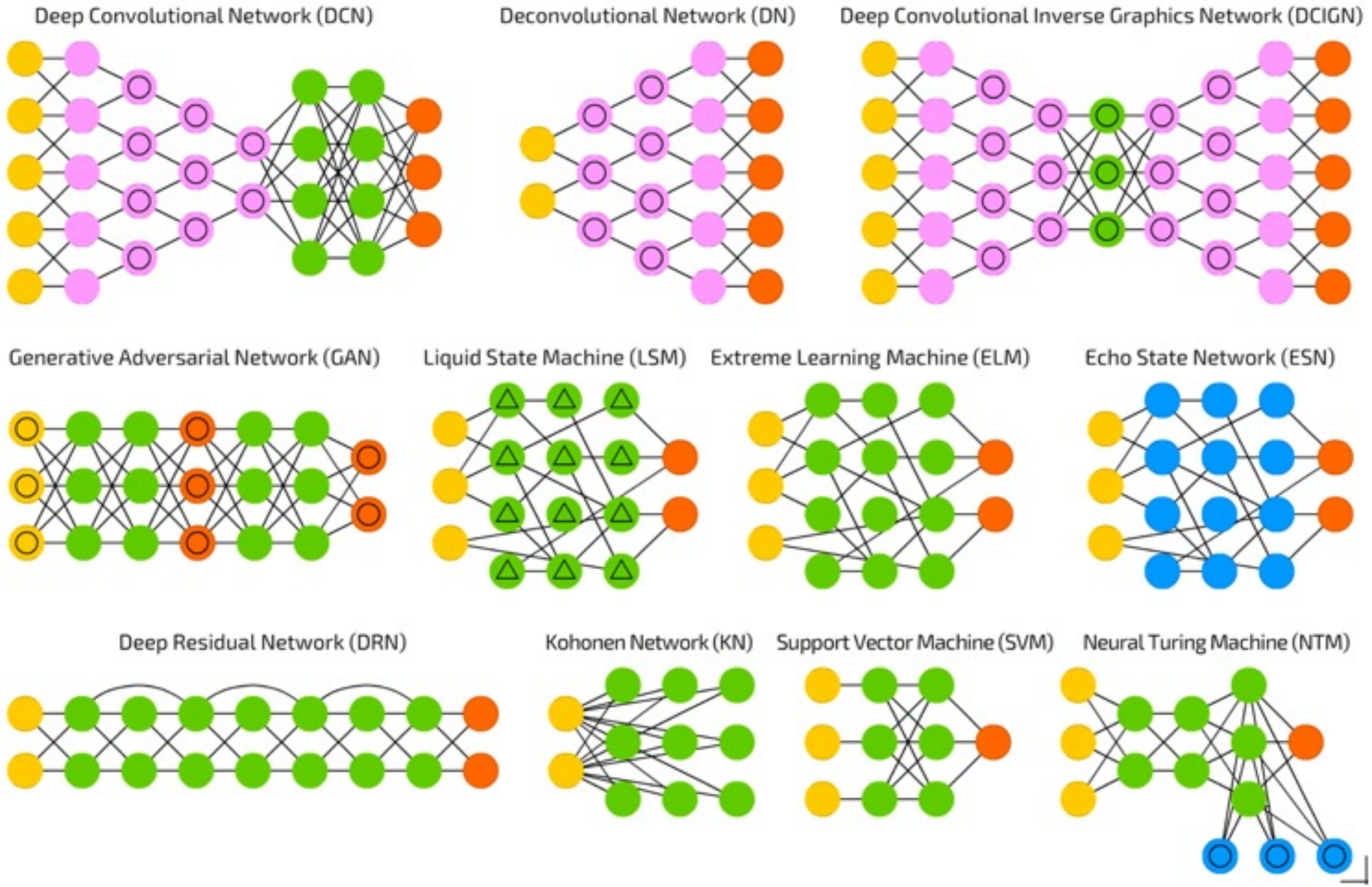
# Neural Networks (NN)




Source: http://www.asimovinstitute.org/neural-network-zoo/

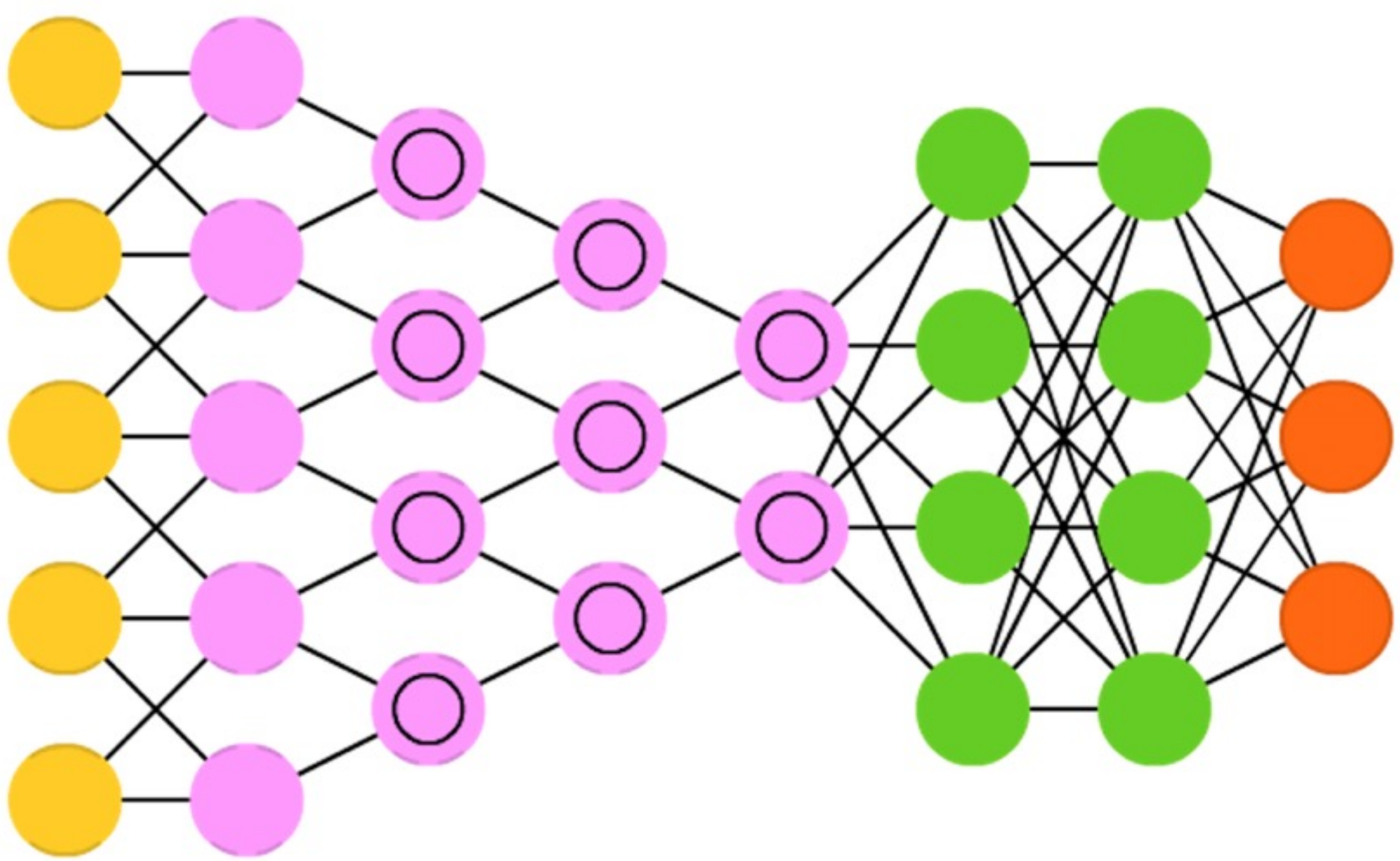



Source: http://www.asimovinstitute.org/neural-network-zoo/




Source: http://www.asimovinstitute.org/neural-network-zoo/

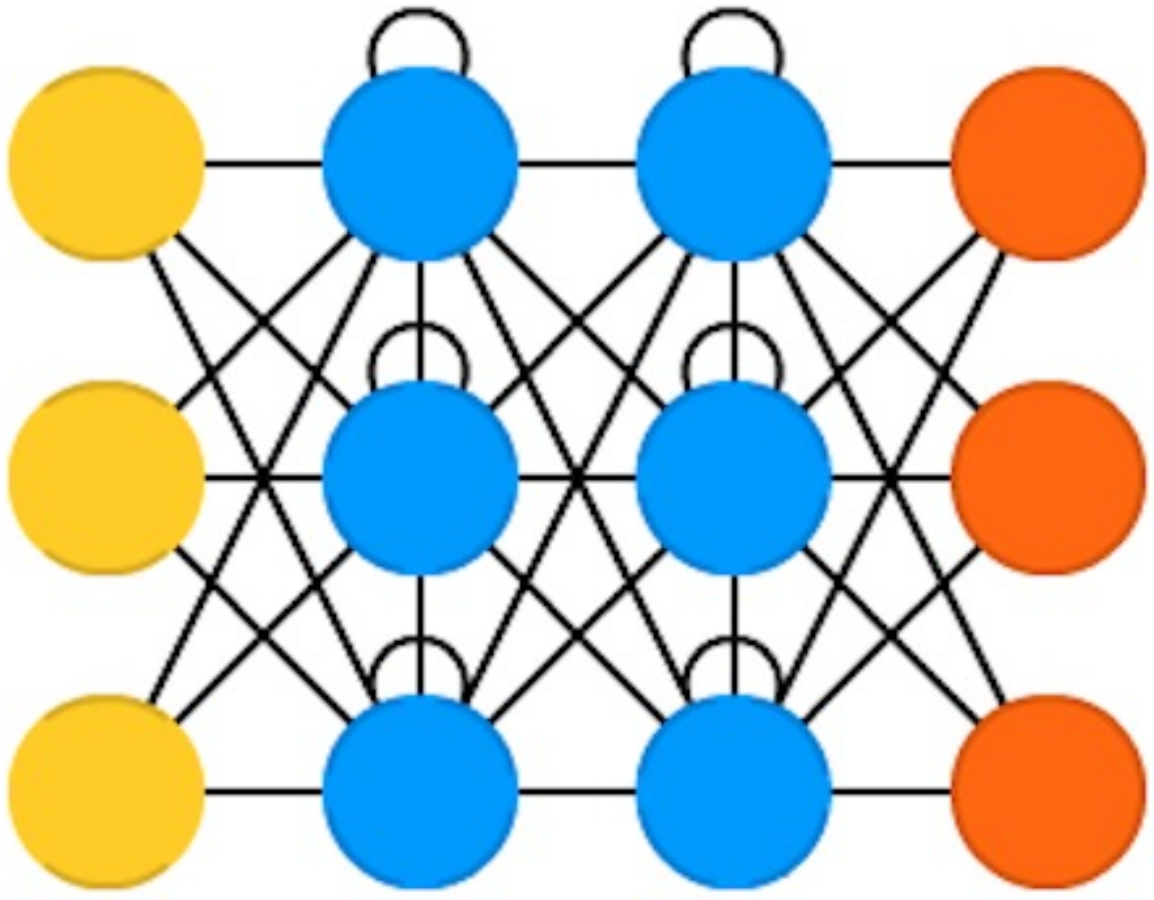
# Convolutional Neural Networks (CNN or Deep Convolutional Neural Networks, DCNN)



LeCun, Yann, et al. "Gradient-based learning applied to document recognition." Proceedings of the IEEE 86.11 (1998): 2278-2324.

Source: http://www.asimovinstitute.org/neural-network-zoo/

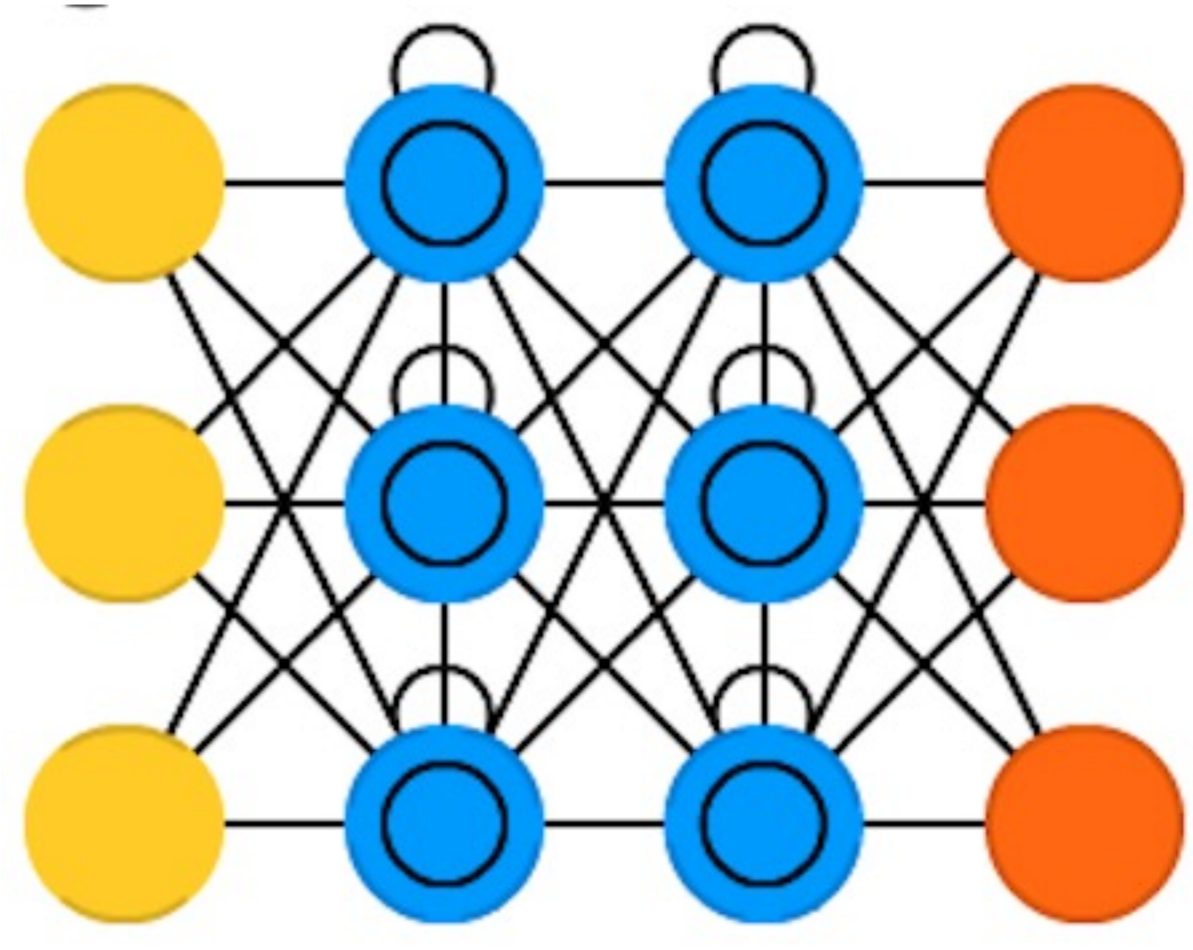
# Recurrent Neural Networks (RNN)



Elman, Jeffrey L. "Finding structure in time." Cognitive science 14.2 (1990): 179-211

Source: http://www.asimovinstitute.org/neural-network-zoo/

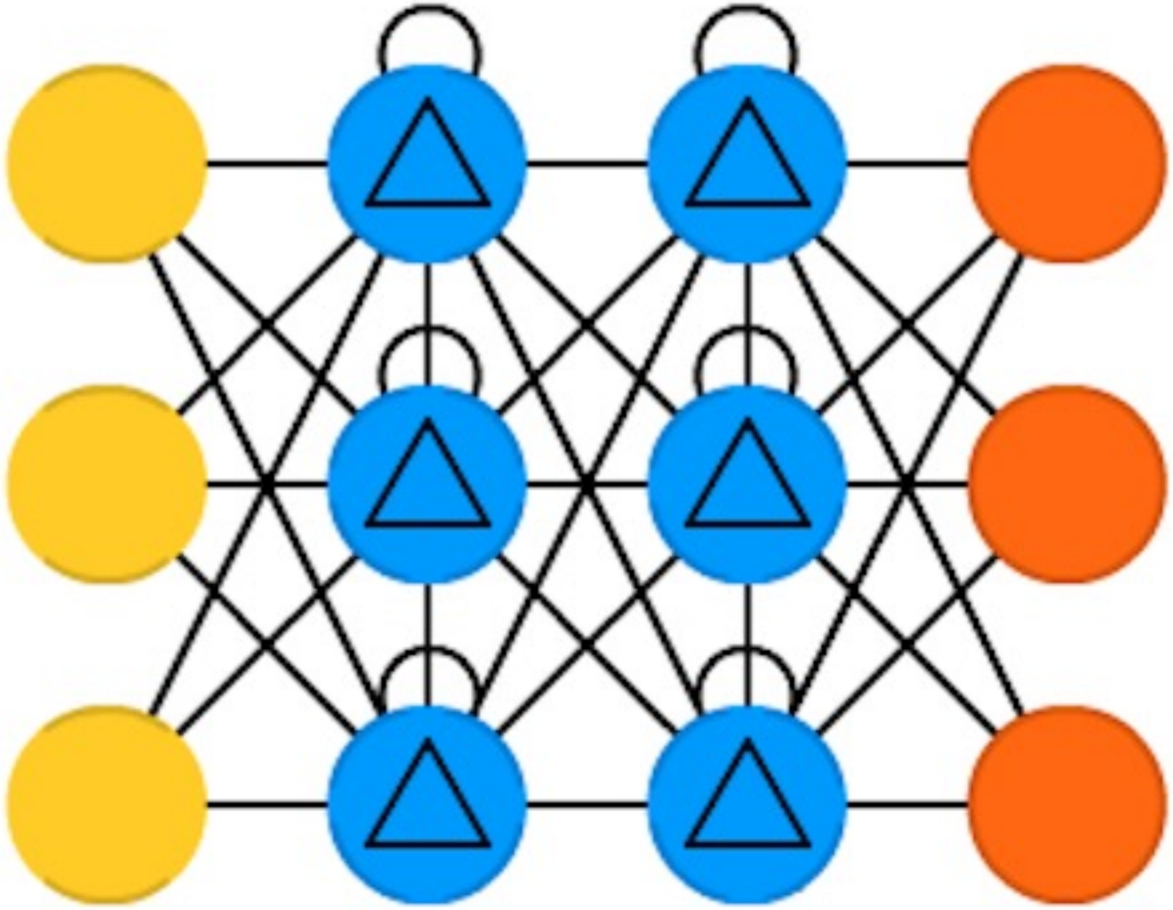
# Long / Short Term Memory (LSTM)



Hochreiter, Sepp, and Jürgen Schmidhuber. “Long short-term memory.” Neural computation 9.8 (1997): 1735-1780.

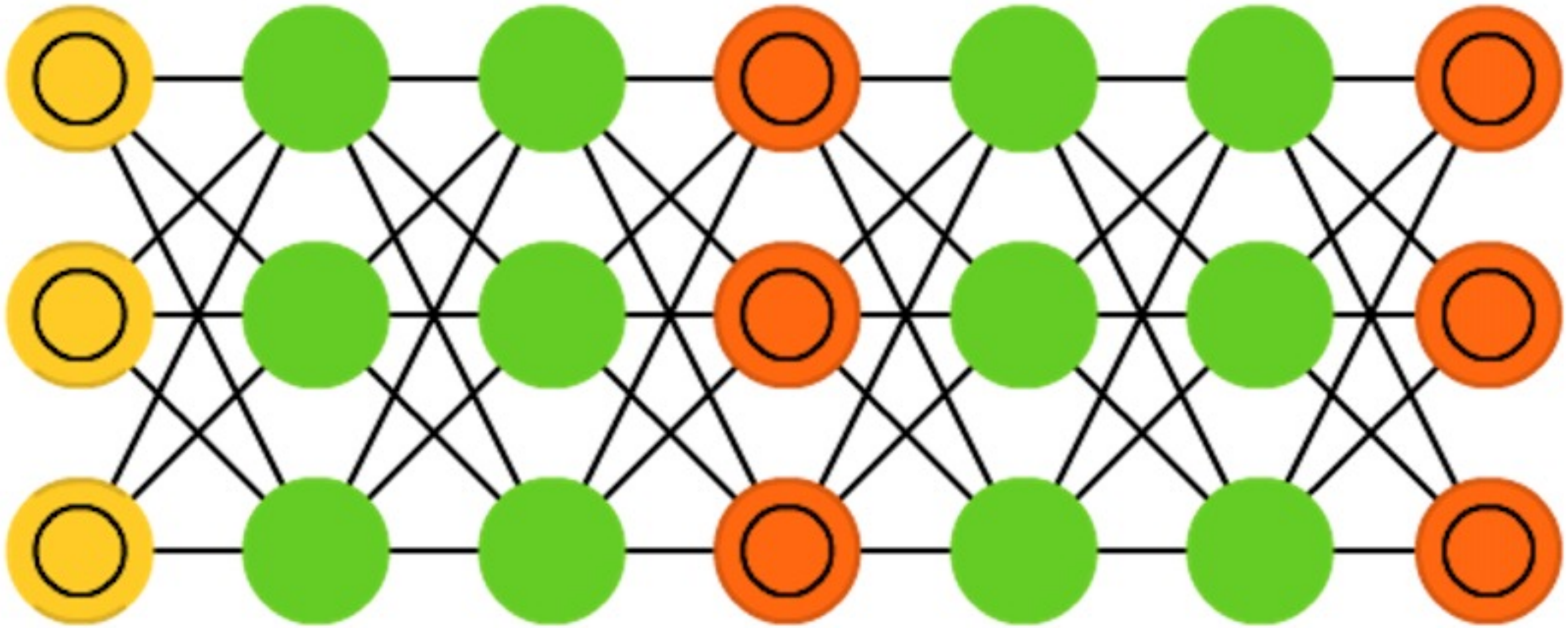
Source: http://www.asimovinstitute.org/neural-network-zoo/

# Gated Recurrent Units (GRU)



Chung, Junyoung, et al. "Empirical evaluation of gated recurrent neural networks on sequence modeling." arXiv preprint arXiv:1412.3555 (2014).
Source: http://www.asimovinstitute.org/neural-network-zoo/

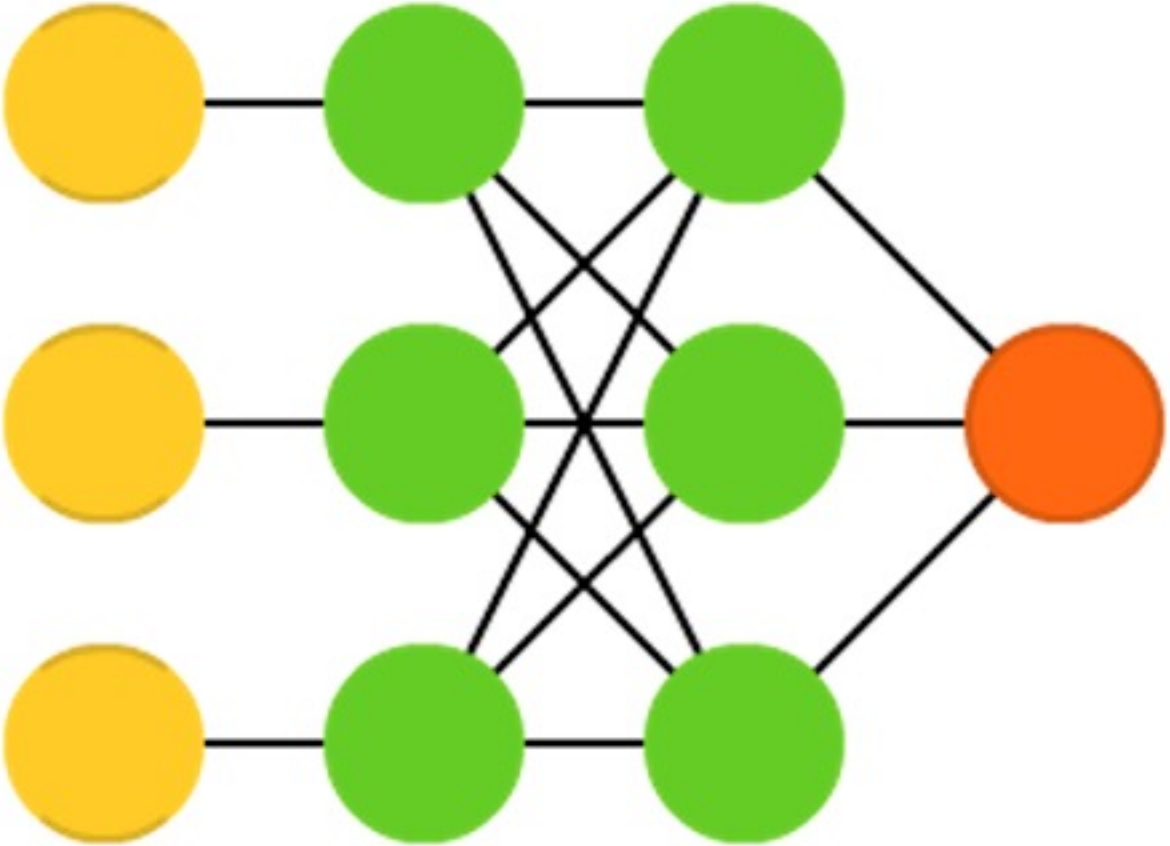
# Generative Adversarial Networks (GAN)



Goodfellow, Ian, et al. “Generative adversarial nets.” Advances in Neural Information Processing Systems. 2014.

Source: http://www.asimovinstitute.org/neural-network-zoo/

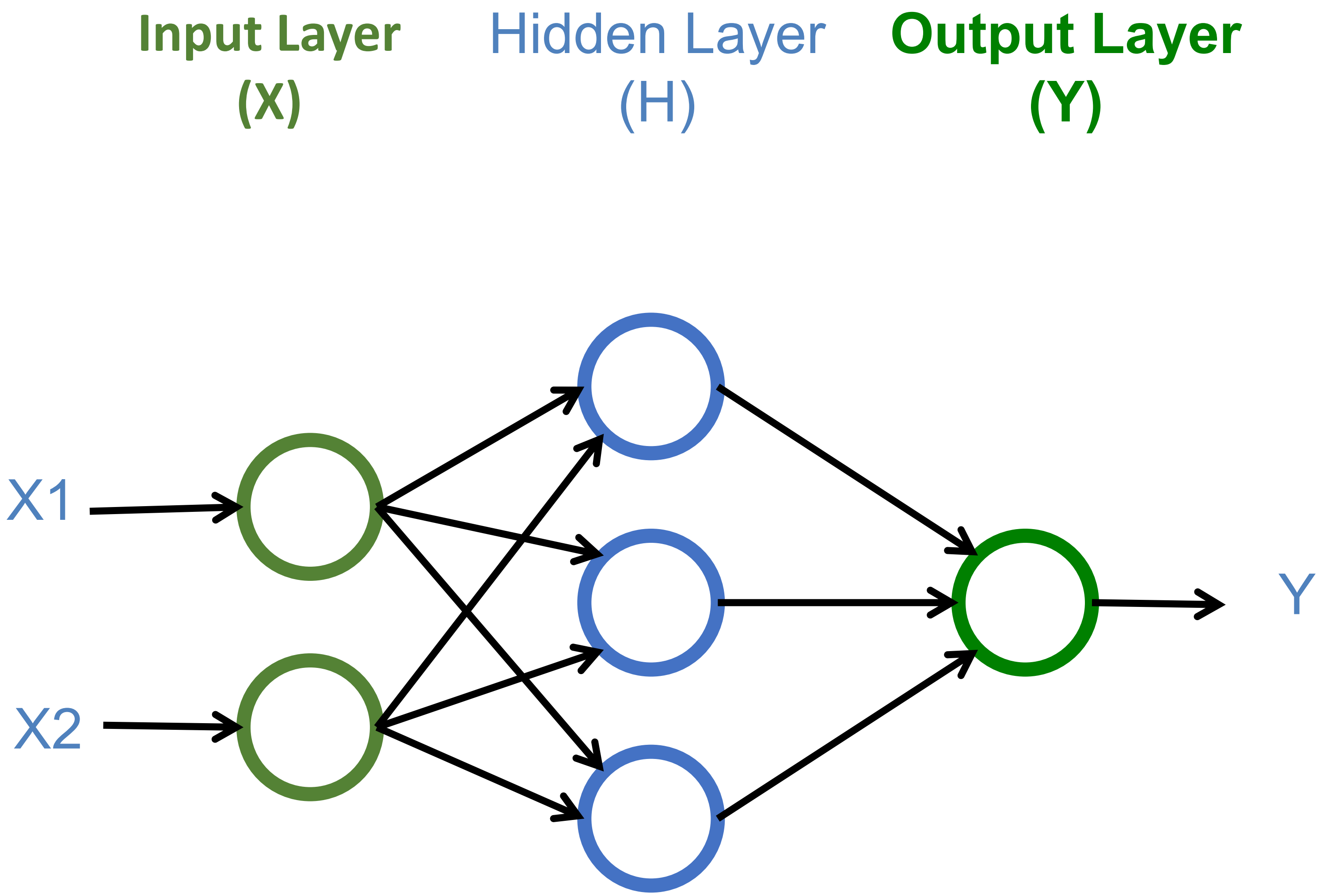
# Support Vector Machines (SVM)



Cortes, Corinna, and Vladimir Vapnik. “Support-vector networks.” Machine learning 20.3 (1995): 273-297.

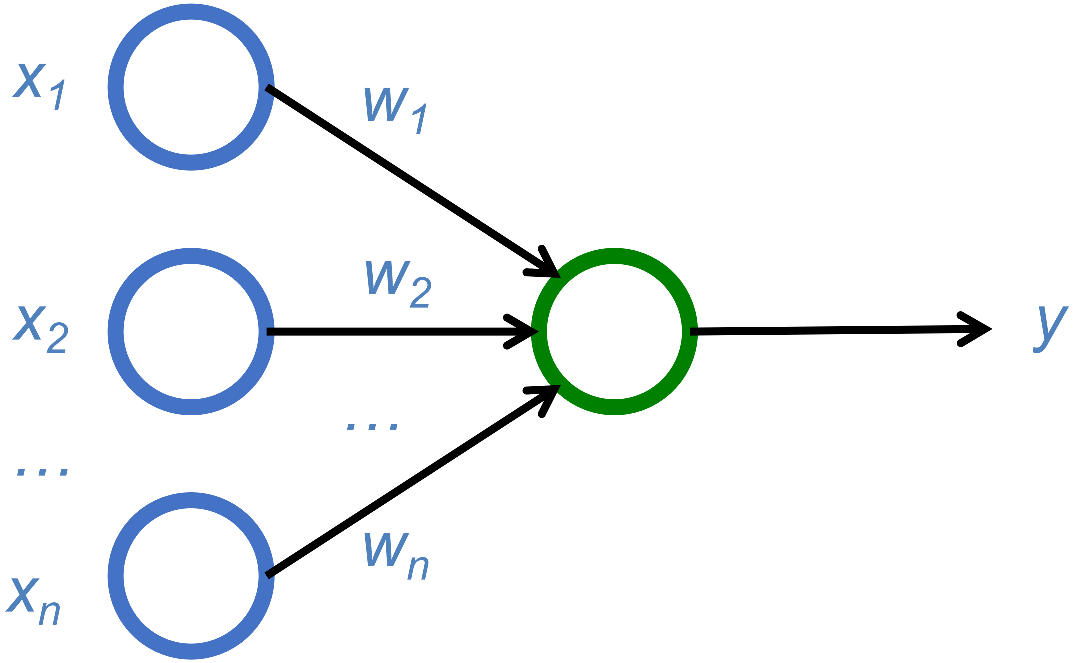
Source: http://www.asimovinstitute.org/neural-network-zoo/

# Neural Networks



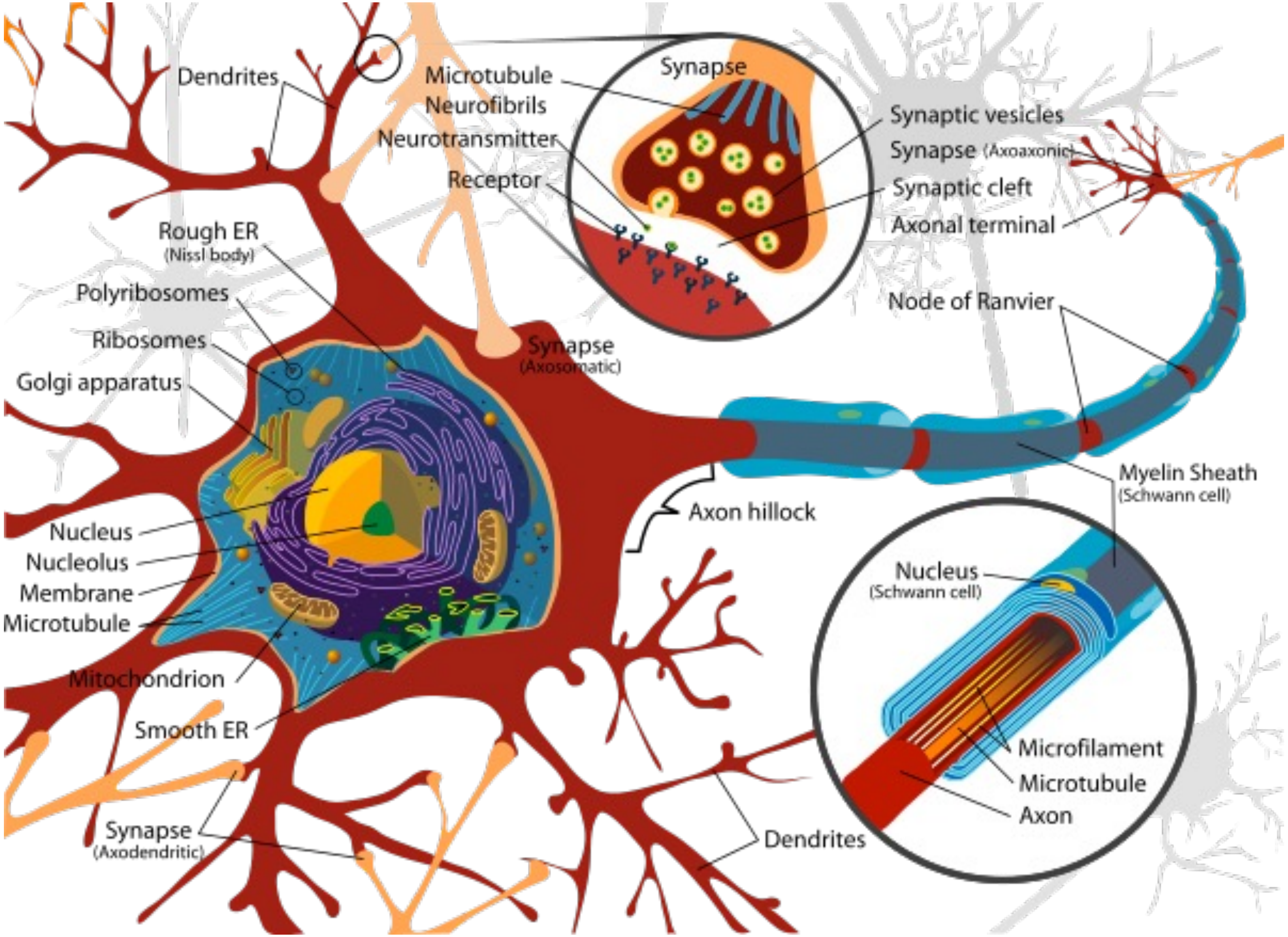

Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

# The Neuron




Source: Jeff Dean (2016), Large-Scale Deep Learning For Building Intelligent Computer Systems, WSDM 2016

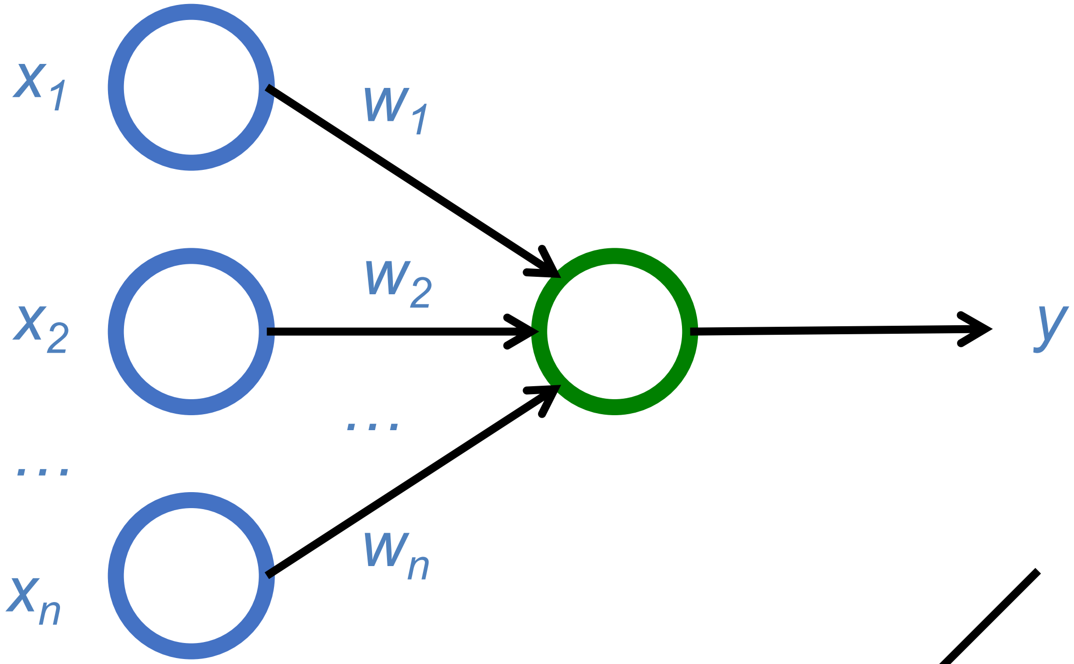
# Neuron and Synapse

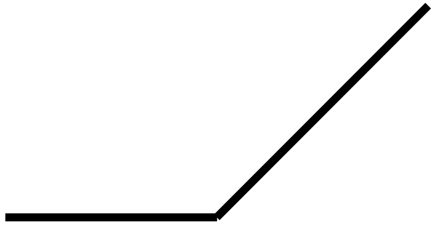



Source: https://en.wikipedia.org/wiki/Neuron

# The Neuron

$$y = F\left(\sum_i w_i x_i\right)$$

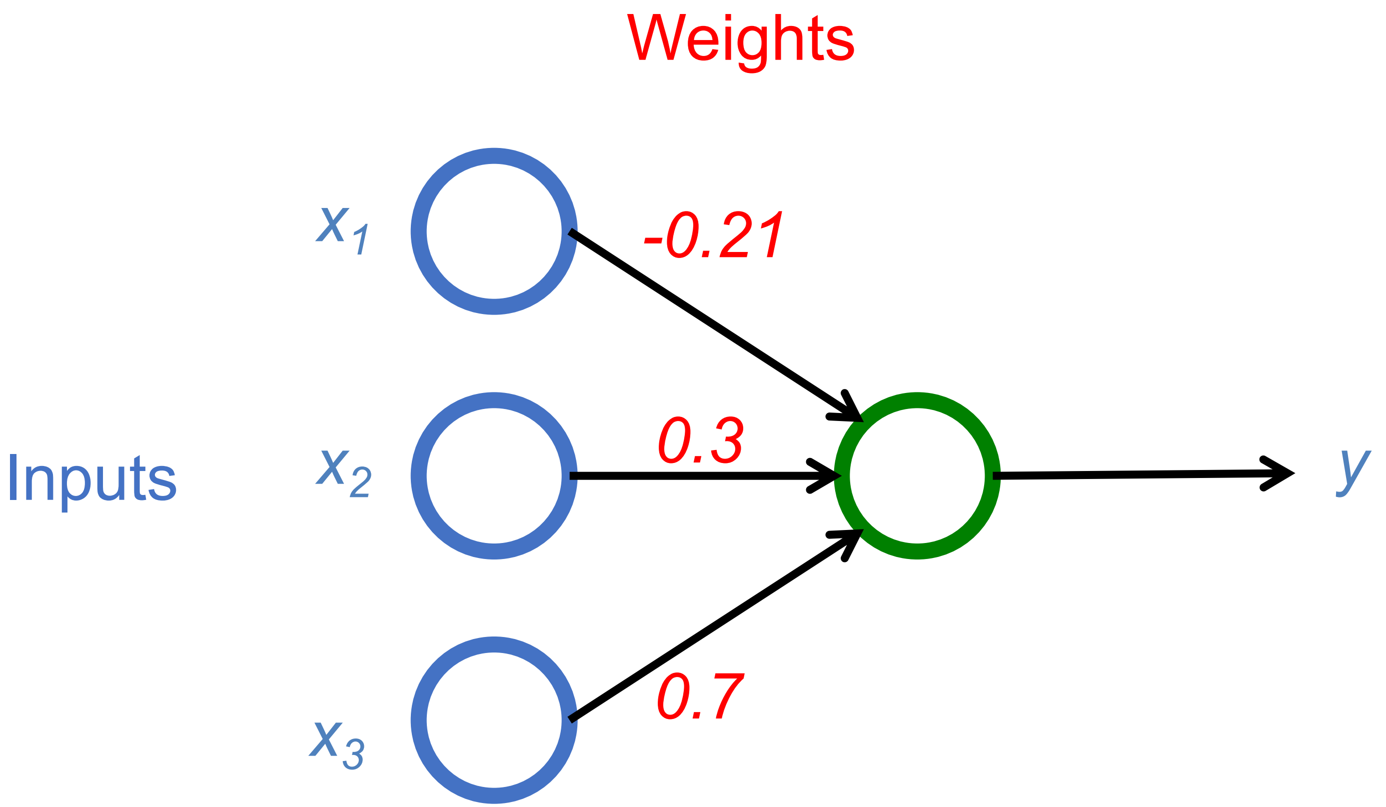


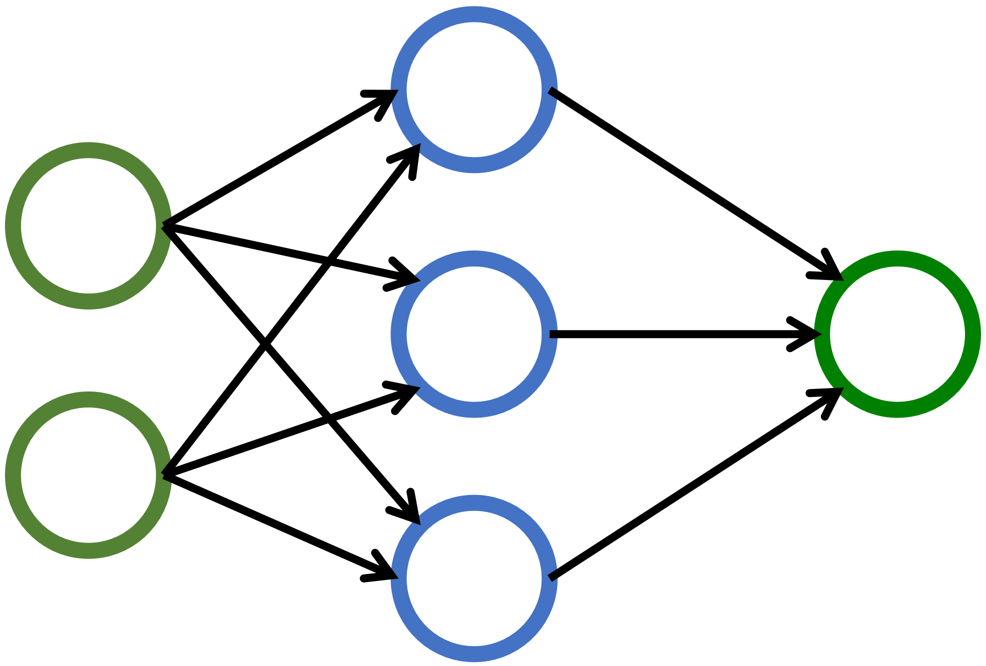
$$F(x) = \max(0, x)$$

Source: Jeff Dean (2016), Large-Scale Deep Learning For Building Intelligent Computer Systems, WSDM 2016

$$y = max(0, -0.21 * x_1 + 0.3 * x_2 + 0.7 * x_3)$$

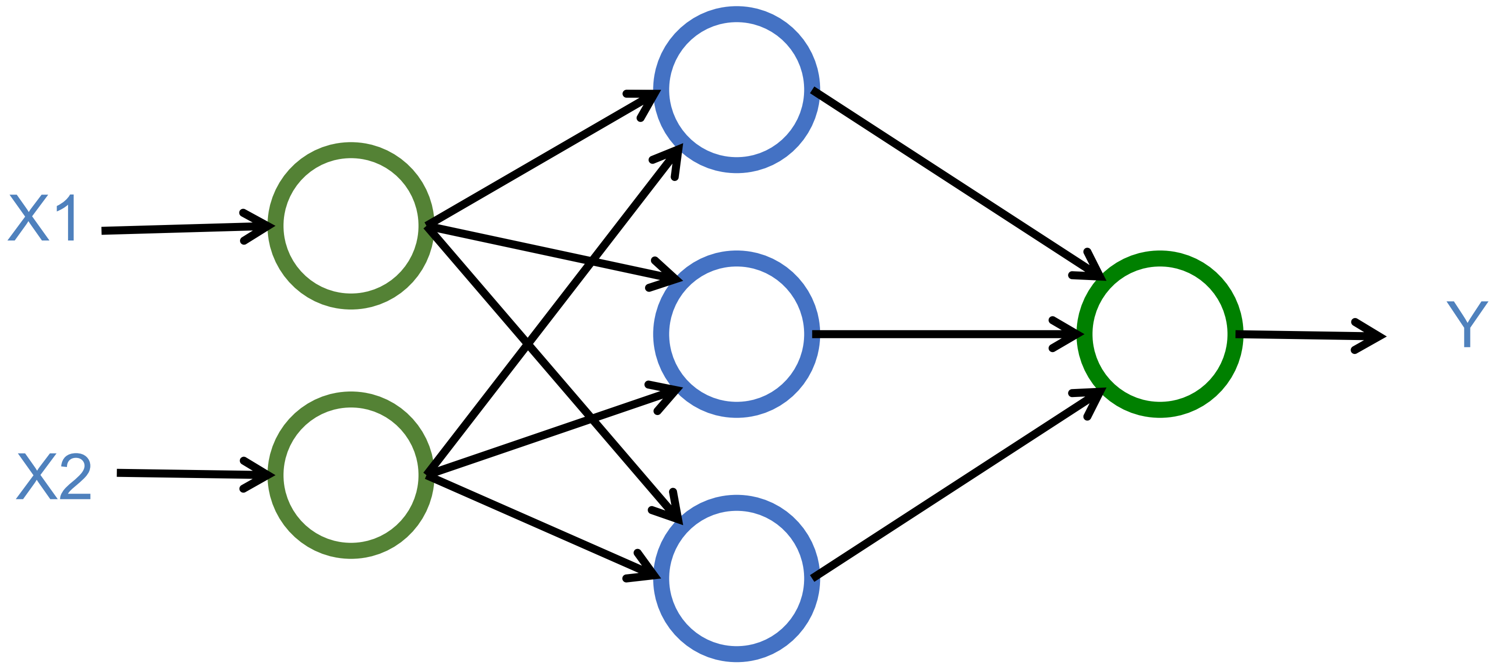


# Neural Networks



# Neural Networks

**Input Layer (X)** | Hidden Layer (H) | **Output Layer (Y)**




Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

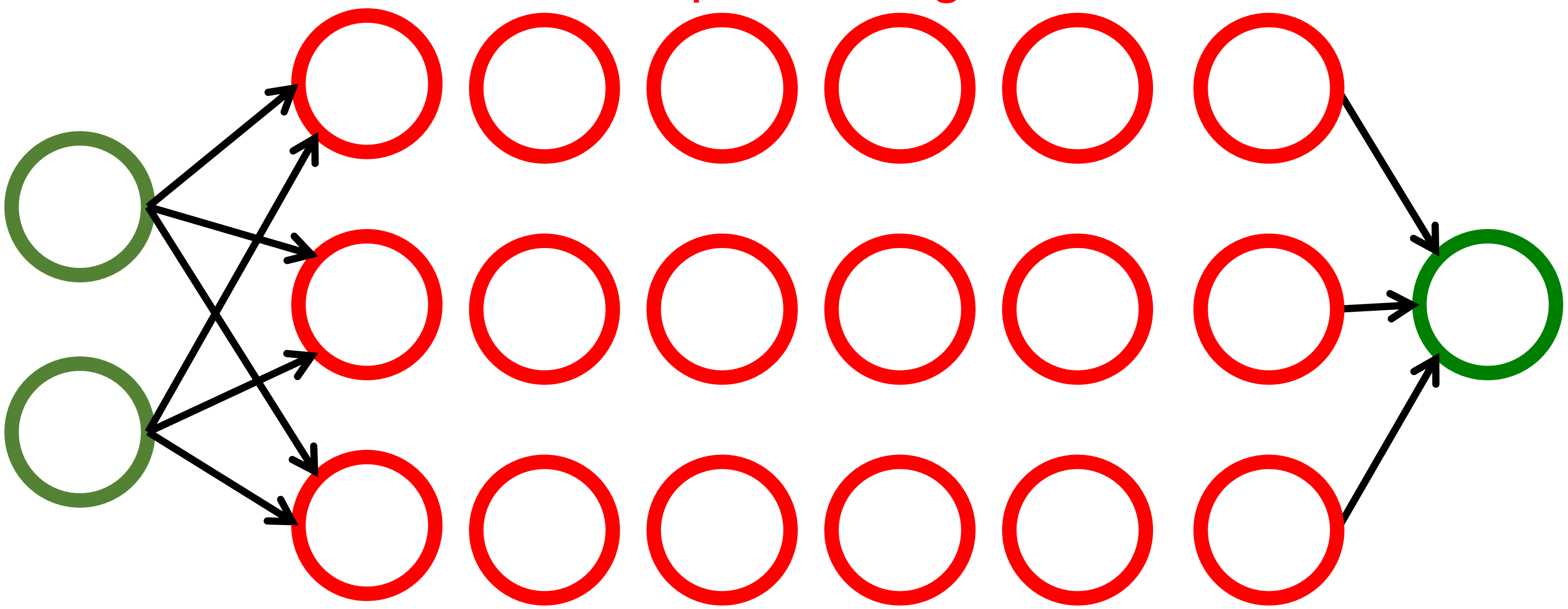
# Neural Networks

Input Layer
(X)

Hidden Layers
(H)

Output Layer
(Y)

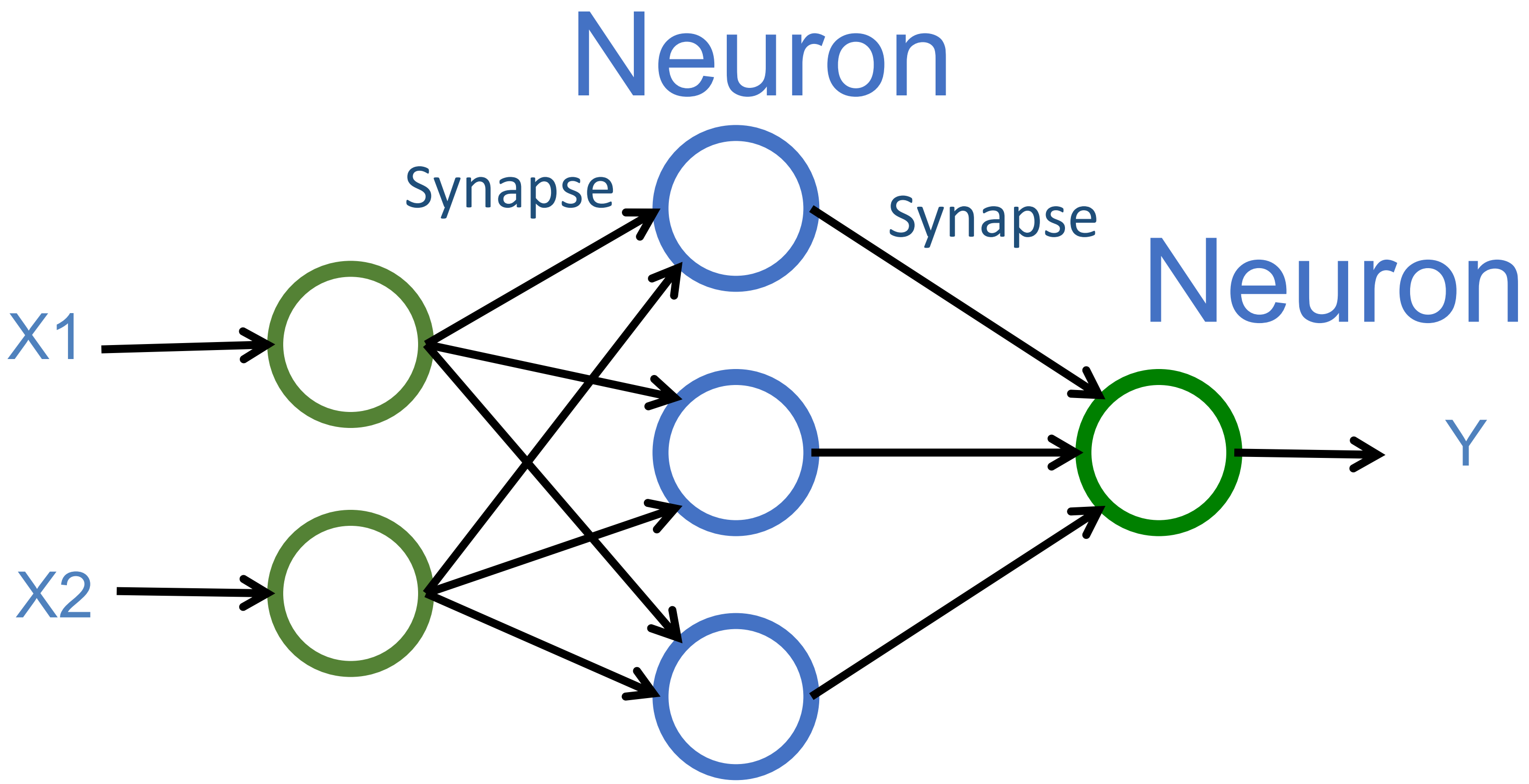
Deep Neural Networks
Deep Learning



Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

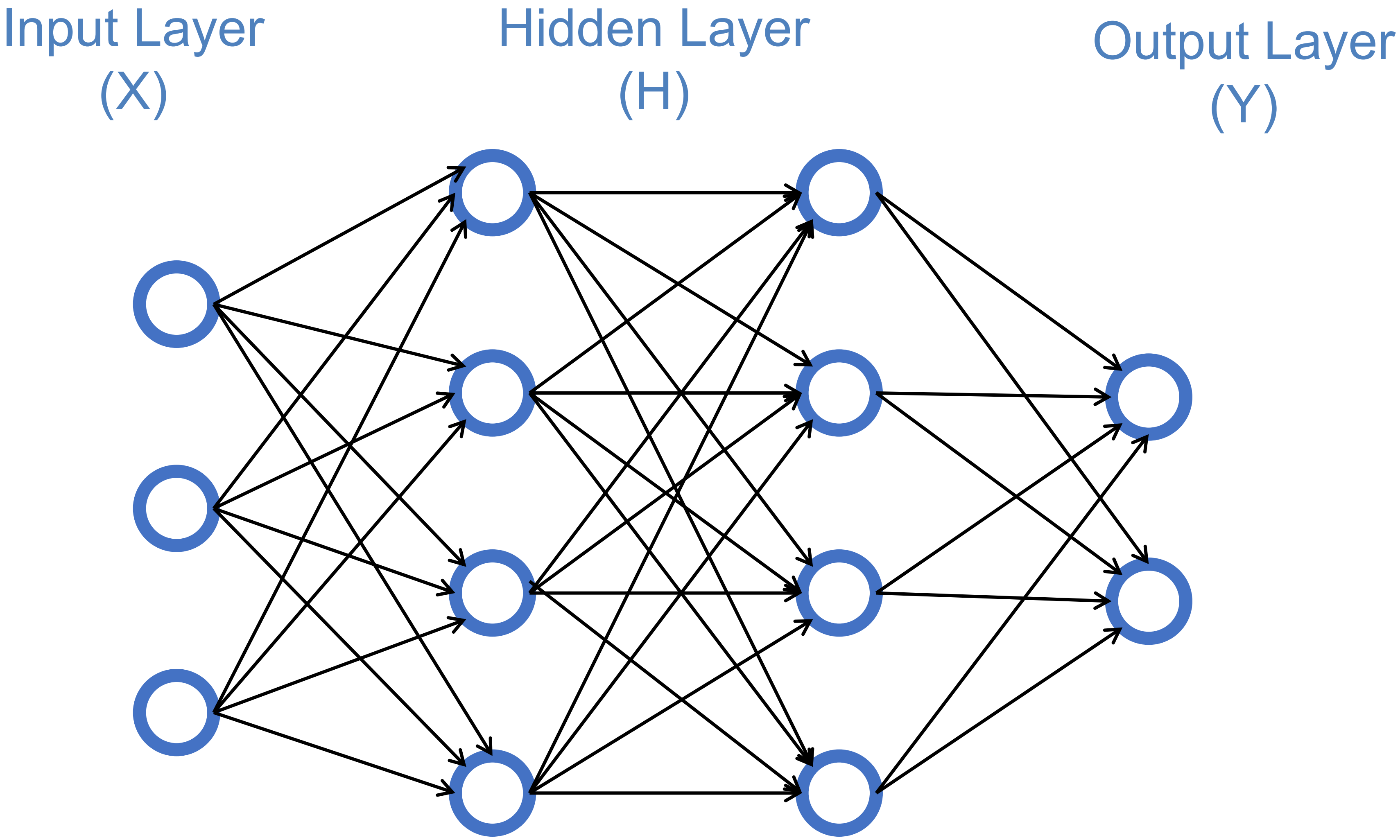
# Neural Networks

**Input Layer (X)** Hidden Layer (H) **Output Layer (Y)**



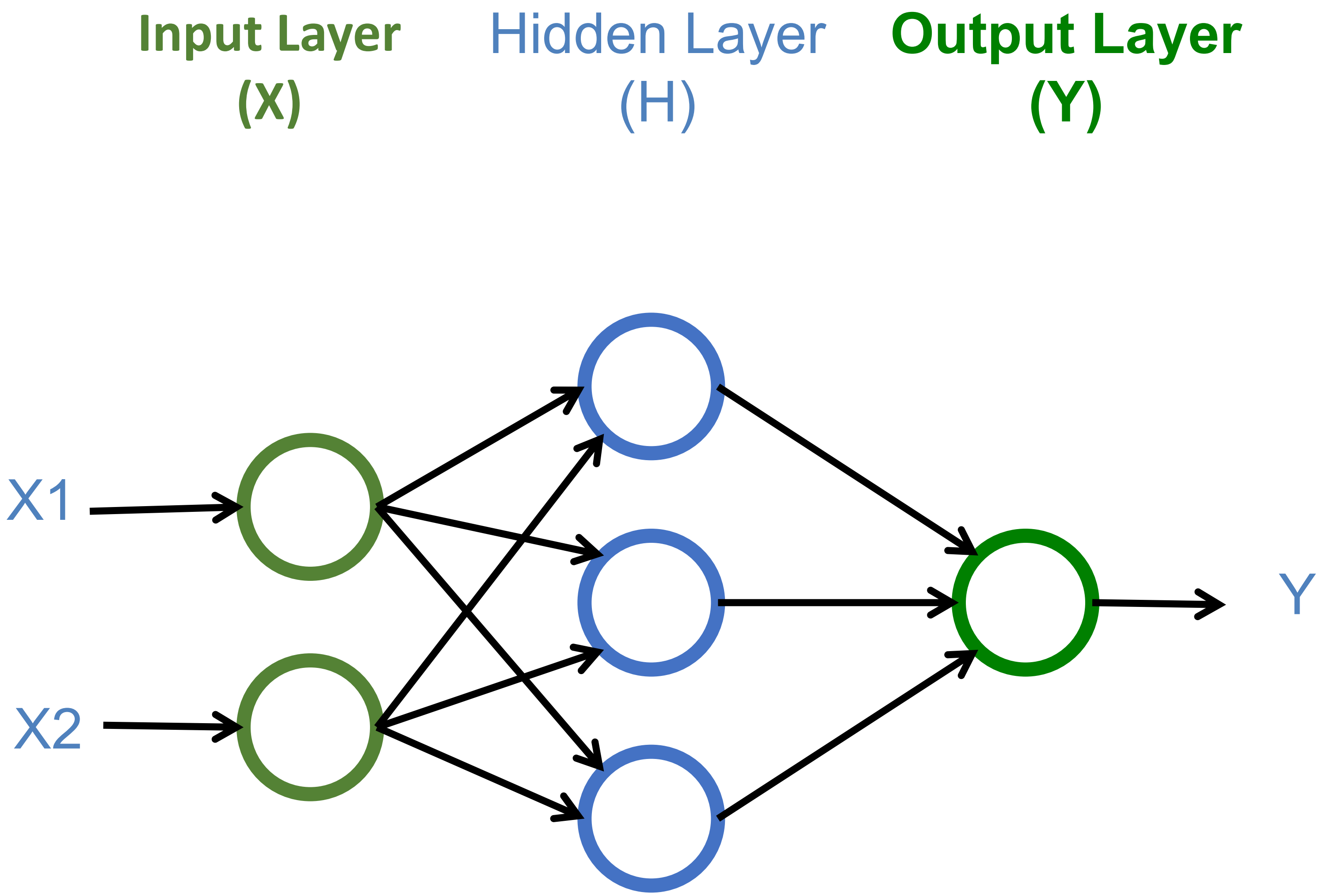

Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

# Neural Networks




Source: https://www.youtube.com/watch?v=P2HPcj8lRJE&list=PLjJh1vlSEYgvGod9wWiydumYl8hOXixNu&index=2

# Neural Networks




Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

# Linear function

$$y = f(x)$$

$$y = w_1 x + w_0$$

$$h_w(x) = w_1 x + w_0$$

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

$$Y = W X + b$$

Source: https://www.youtube.com/watch?v=G8eNWzxOgqE

Output

input

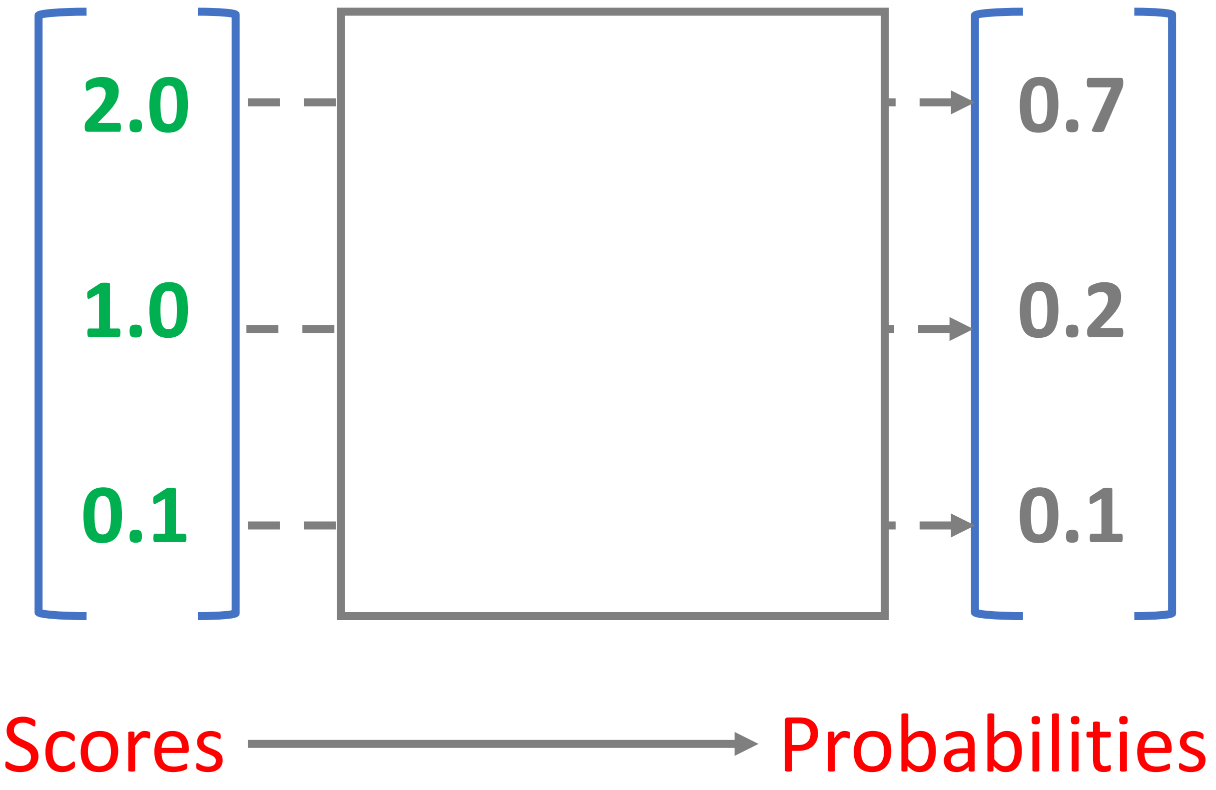
$$Y = W X + b$$

Weights

bias

Trained

$$WX + b = Y$$




Source: https://www.youtube.com/watch?v=G8eNWzxOgqE

# SoftMAX

**W X + b = Y**

$$\begin{bmatrix} 2.0 \\ 1.0 \\ 0.1 \end{bmatrix} \rightarrow S(y_i) = \frac{e^{y_i}}{\sum_j e^{y_j}} \rightarrow \begin{bmatrix} 0.7 \\ 0.2 \\ 0.1 \end{bmatrix}$$

**Logits**

Scores → Probabilities

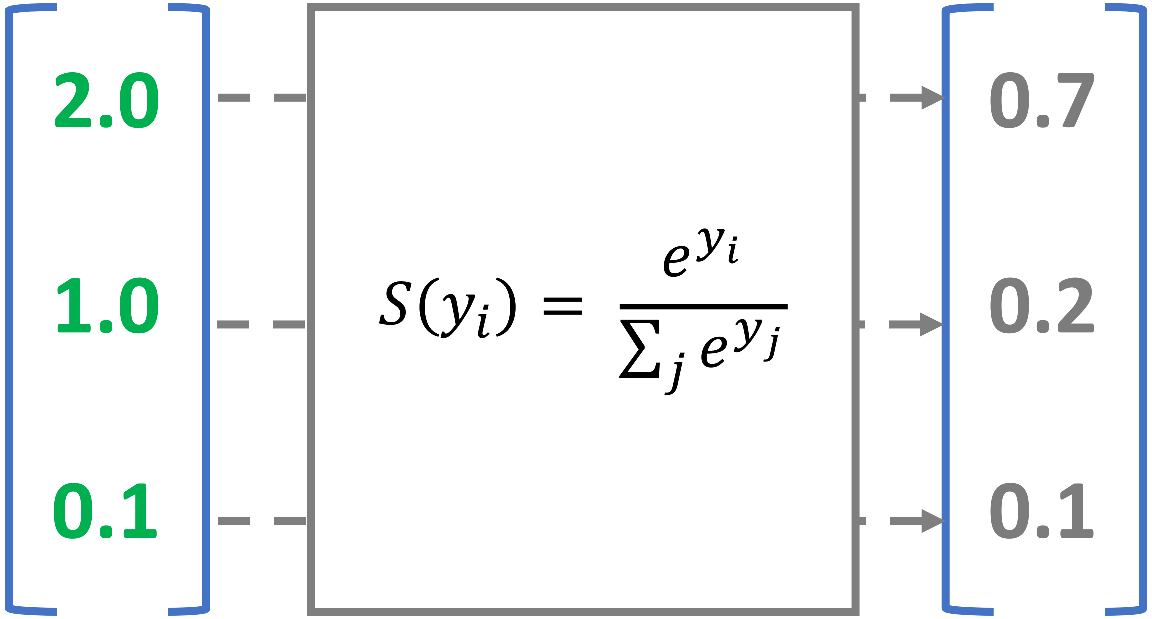
Source: https://www.youtube.com/watch?v=G8eNWzxOgqE

$$S(y_i) = \frac{e^{y_i}}{\sum_j e^{y_i}} = \frac{e^{2.0}}{e^{2.0}+e^{1.0}+e^{0.1}} = \frac{2.7182^{2.0}}{2.7182^{2.0}+2.7182^{1.0}+2.7182^{0.1}} = 0.7$$

$$S(y_i) = \frac{e^{y_i}}{\sum_j e^{y_j}} = \frac{e^{1.0}}{e^{2.0}+e^{1.0}+e^{0.1}} = \frac{2.7182^{1.0}}{2.7182^{2.0}+2.7182^{1.0}+2.7182^{0.1}} = 0.2$$

$$S(y_i) = \frac{e^{y_i}}{\sum_j e^{y_j}} = \frac{e^{0.1}}{e^{2.0}+e^{1.0}+e^{0.1}} = \frac{2.7182^{0.1}}{2.7182^{2.0}+2.7182^{1.0}+2.7182^{0.1}} = 0.1$$

**W X + b = Y**




**Logits**

Scores → Probabilities

# Training a Network
# =
# Minimize the Cost Function

# Training a Network

=

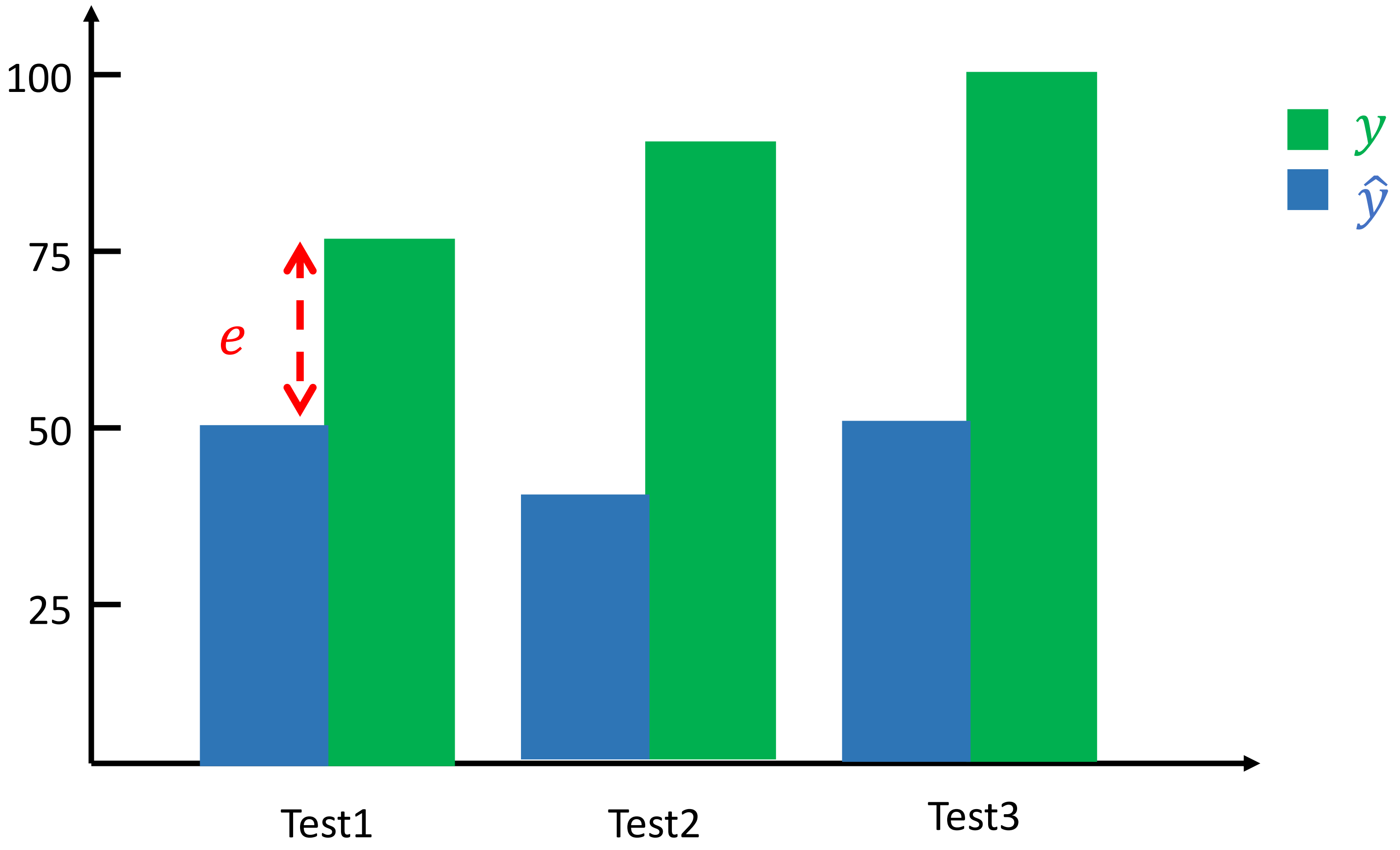
**Minimize the Cost Function**

**Minimize the Loss Function**

Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

# Error = Predict Y - Actual Y

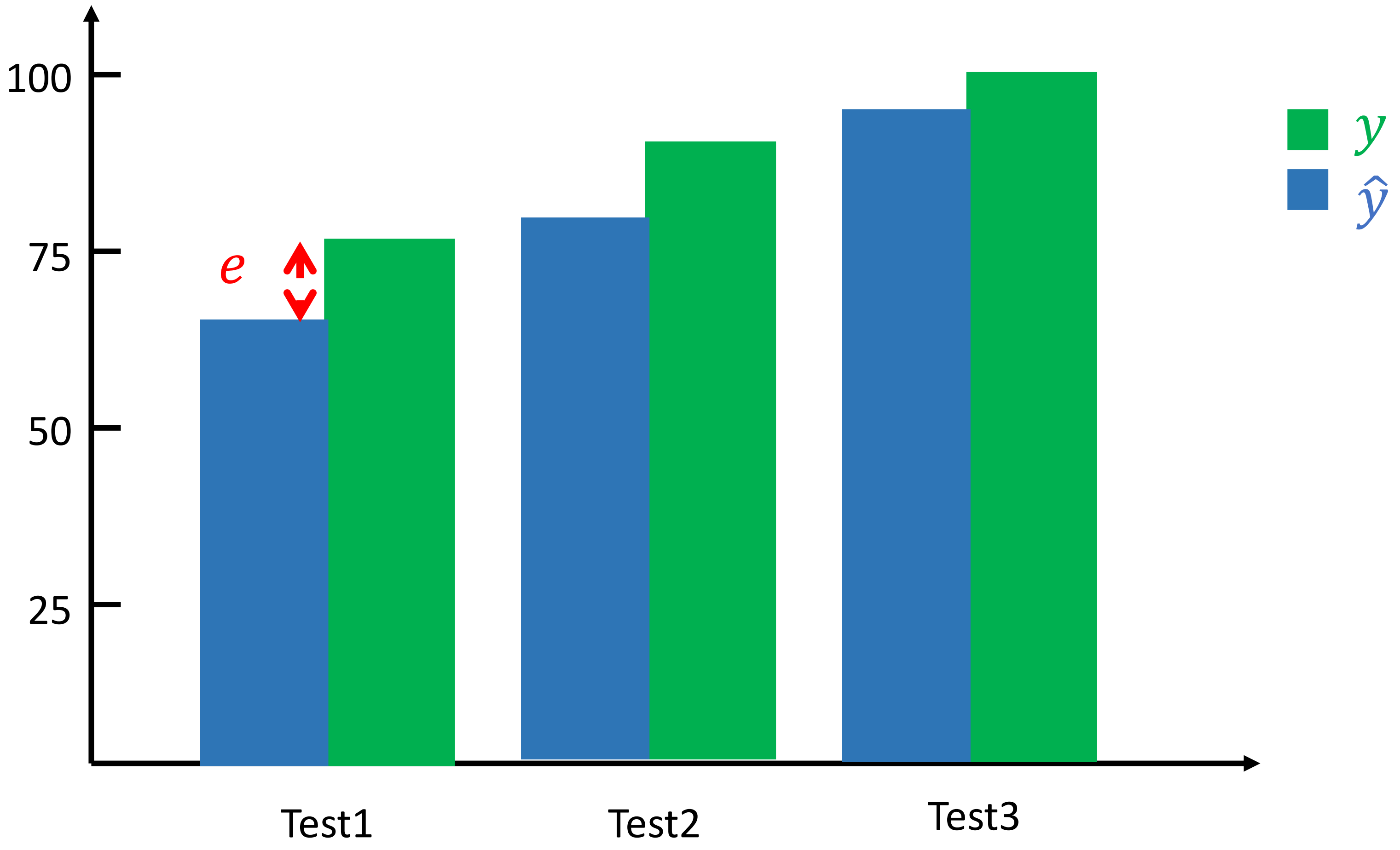
# Error : Cost : Loss




Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

# Error = Predict Y - Actual Y

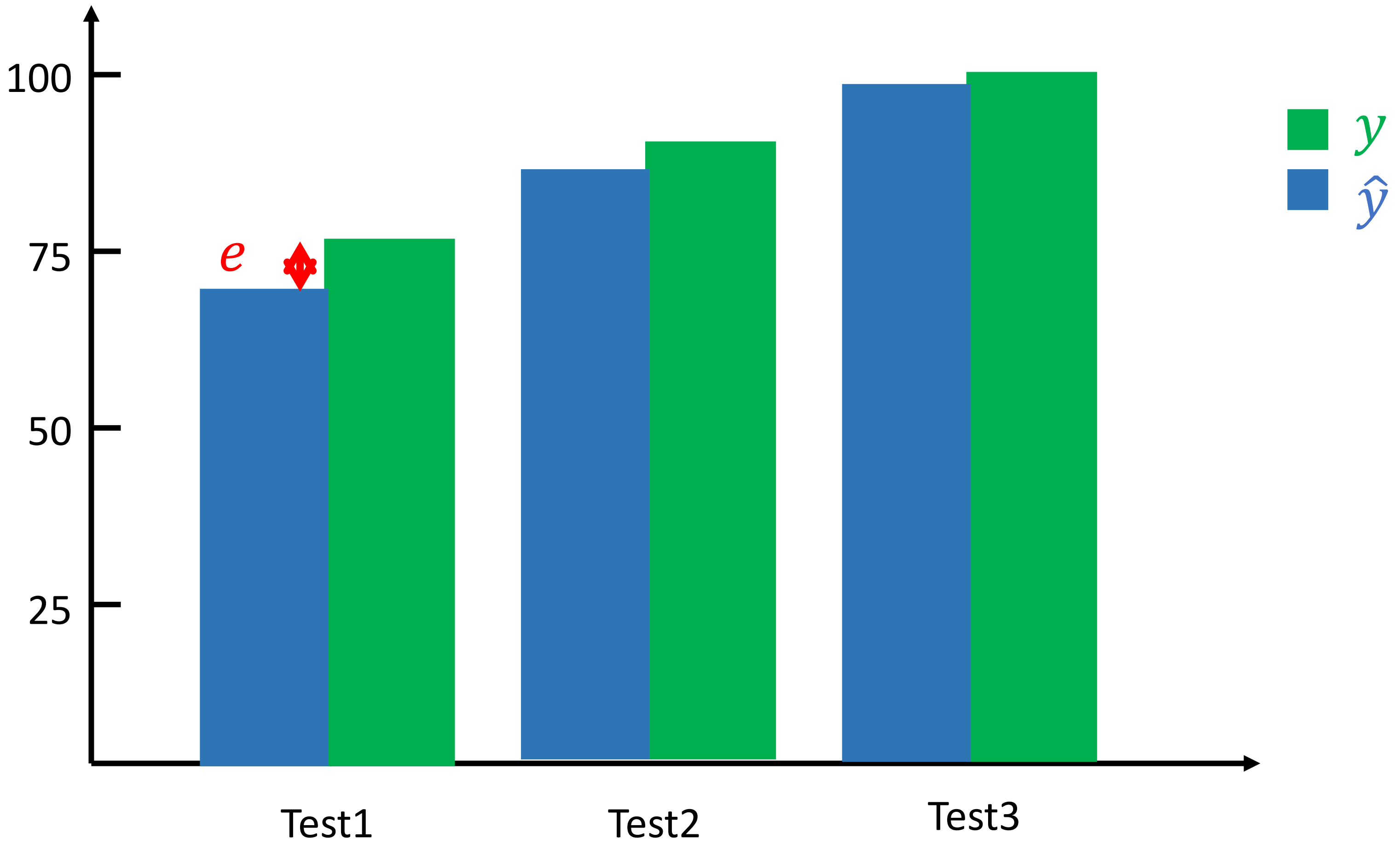
# Error : Cost : Loss




Source: https://www.youtube.com/watch?v=bxe2T-V8XRs&index=1&list=PLiaHhY2iBX9hdHaRr6b7XevZtgZRa1PoU

# Error = Predict Y - Actual Y

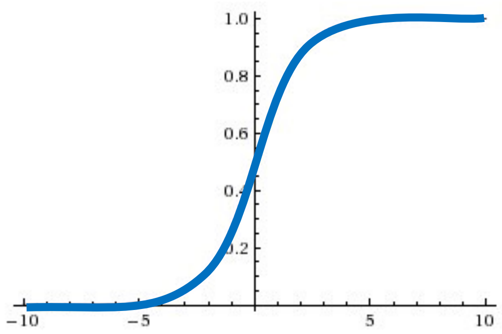
# Error : Cost : Loss



# Activation Functions

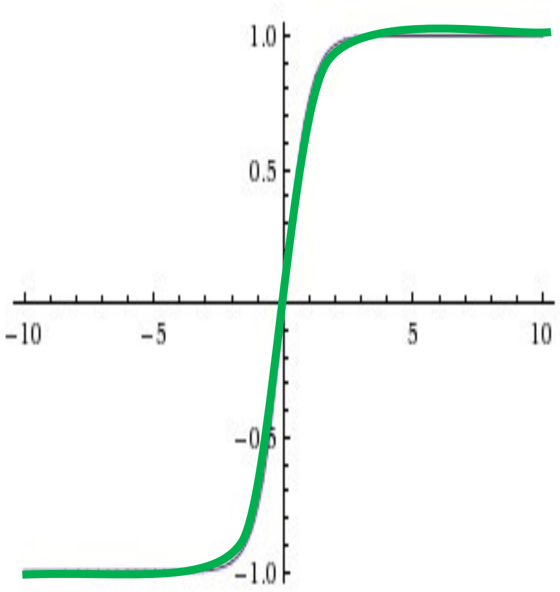
# Activation Functions

## Sigmoid




[0, 1]

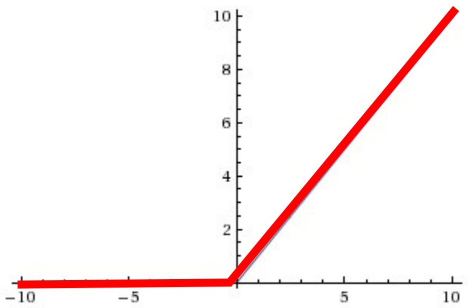
## TanH




[-1, 1]

## ReLU

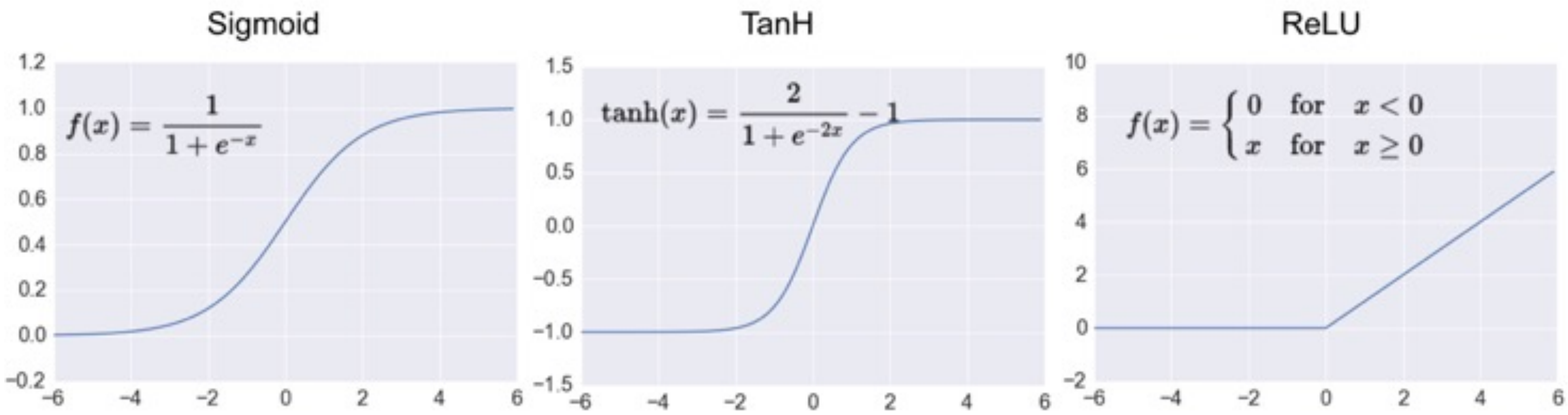
(Rectified Linear Unit)




$f(x) = max(0, x)$

Source: http://cs231n.github.io/neural-networks-1/

# Activation Functions




Source: http://adilmoujahid.com/posts/2016/06/introduction-deep-learning-python-caffe/

# Loss Function

# Binary Classification: 2 Class

## Activation Function:
## Sigmoid

## Loss Function:
## Binary Cross-Entropy

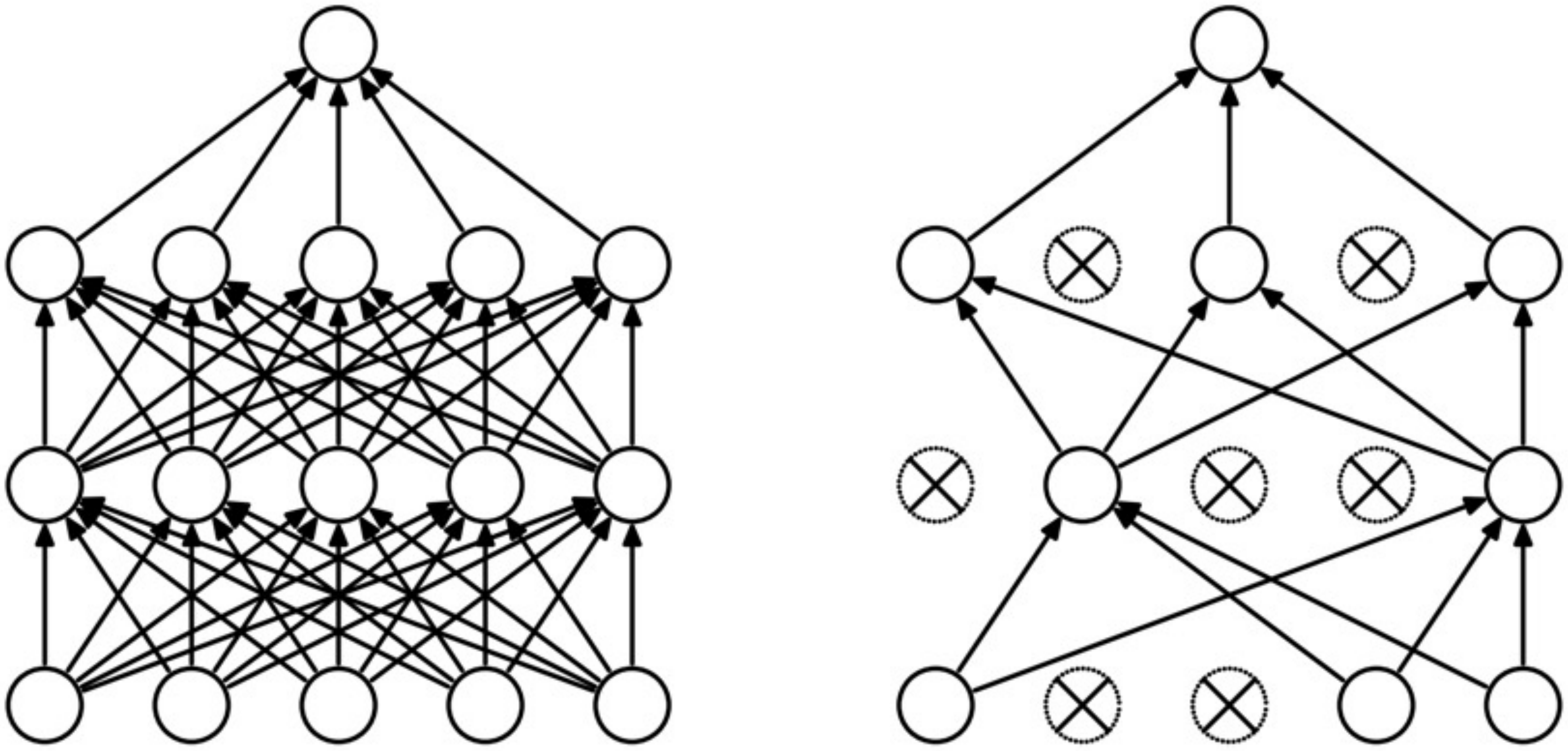
# Multiple Classification: 10 Class

## Activation Function:
## SoftMAX

## Loss Function:
## Categorical Cross-Entropy

# Dropout

Dropout: a simple way to prevent neural networks from overfitting



(a) Standard Neural Net

(b) After applying dropout.

Source: Srivastava, Nitish, Geoffrey E. Hinton, Alex Krizhevsky, Ilya Sutskever, and Ruslan Salakhutdinov.
"Dropout: a simple way to prevent neural networks from overfitting." *Journal of machine learning research* 15, no. 1 (2014): 1929-1958.

# Learning Algorithm

**While not done:**

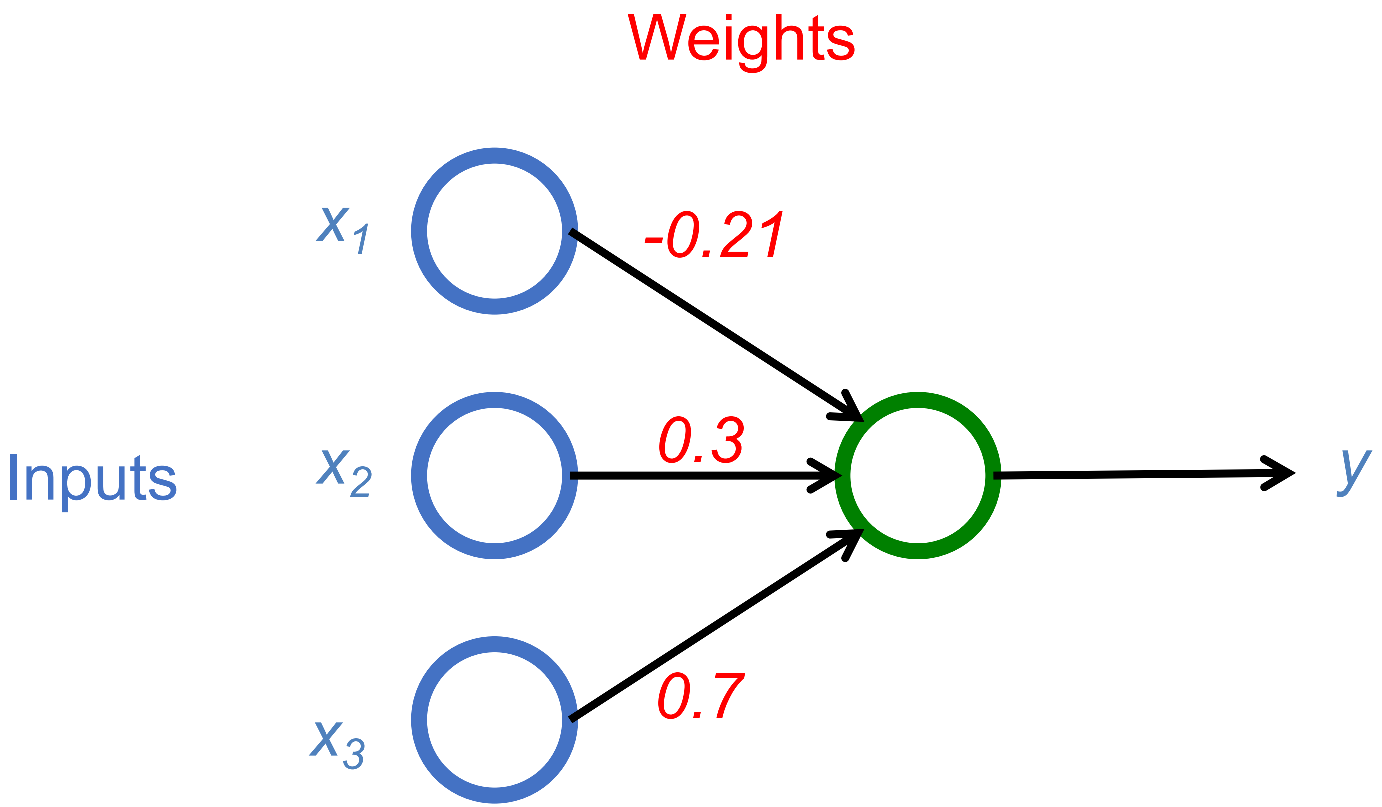
**Pick a random training example "(input, label)"**

**Run neural network on "input"**

**Adjust weights on edges to make output closer to "label"**

Source: Jeff Dean (2016), Large-Scale Deep Learning For Building Intelligent Computer Systems, WSDM 2016

$$y = max\,(\,0,\ -0.21 * x_1 + 0.3 * x_2 + 0.7 * x_3\,)$$



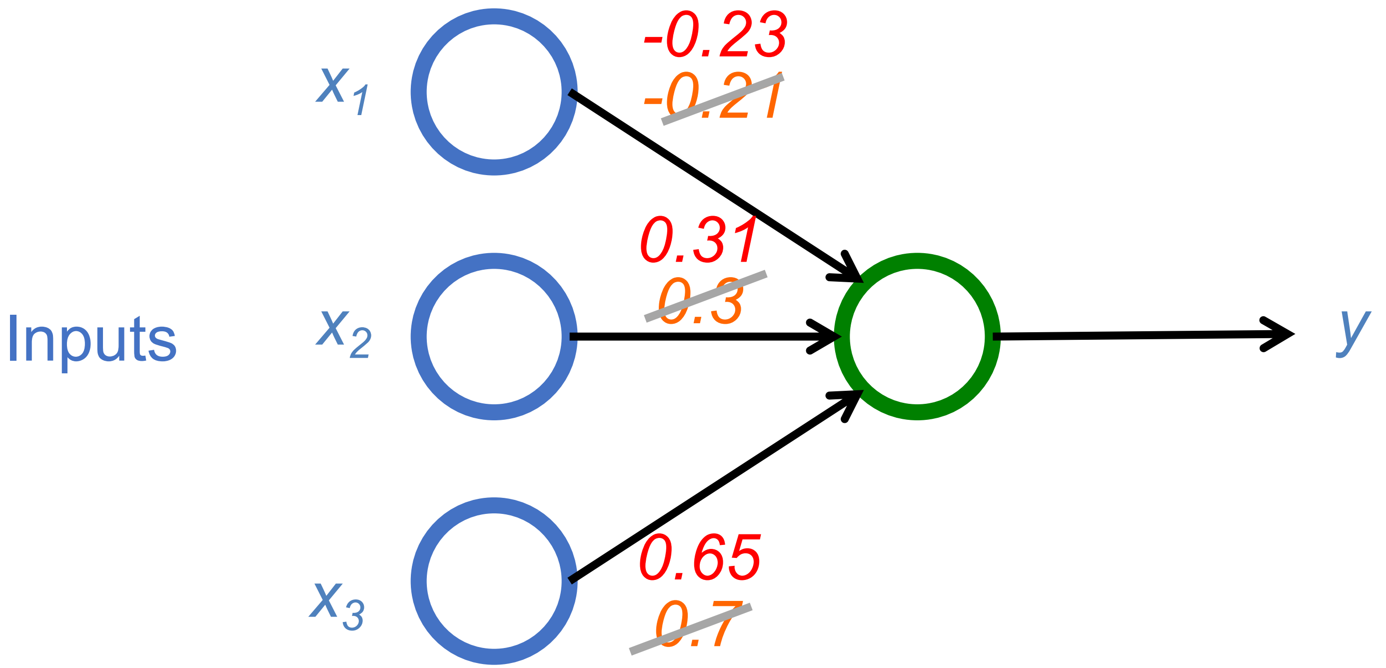

Source: Jeff Dean (2016), Large-Scale Deep Learning For Building Intelligent Computer Systems, WSDM 2016

# Next time:

$$y = max\ (\ 0,\ -0.23\ *\ x_1 + 0.31\ *\ x_2 + 0.65\ *\ x_3\ )$$

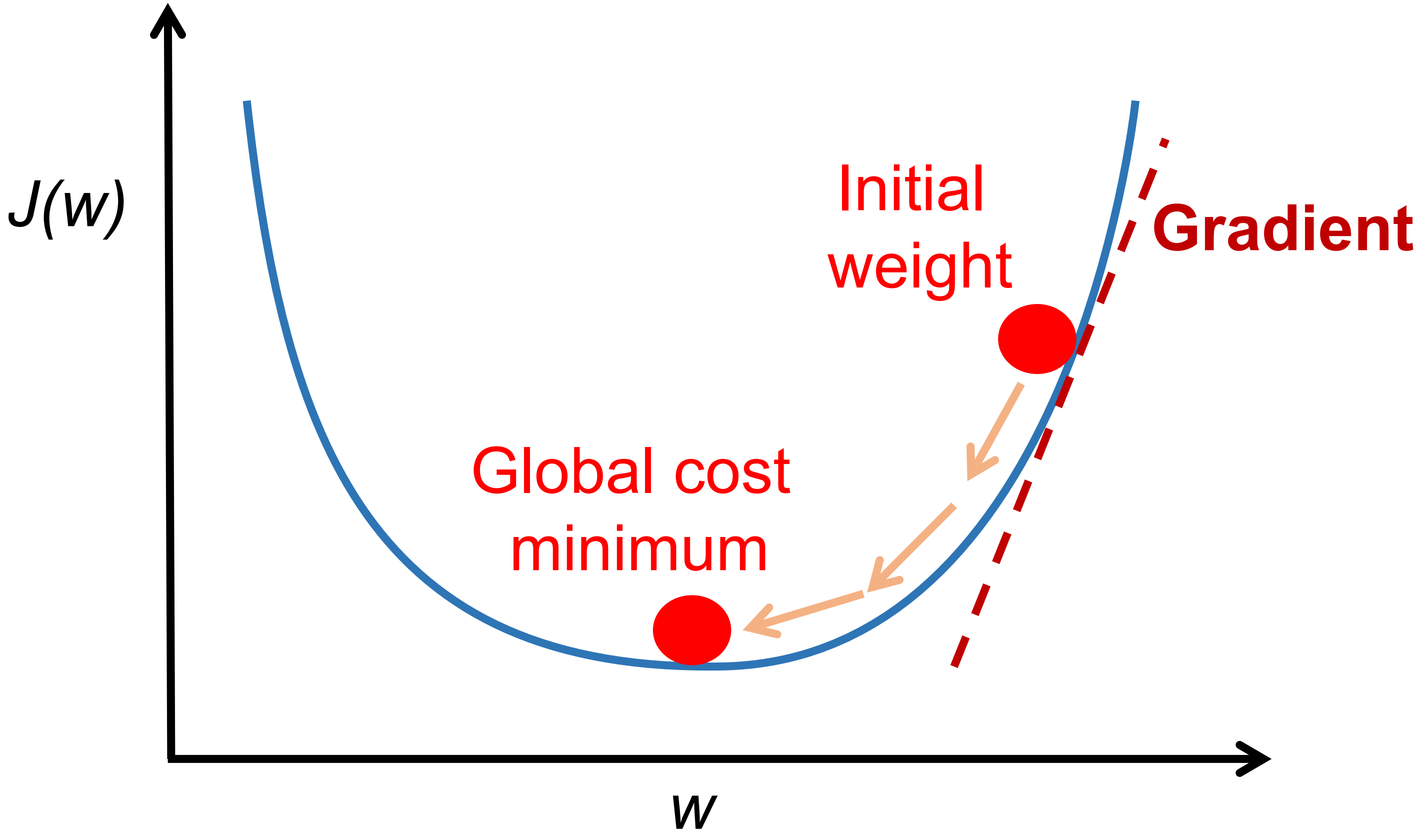
~~$y = max\ (\ 0,\ -0.21\ *\ x_1 + 0.3\ *\ x_2 + 0.7\ *\ x_3\ )$~~

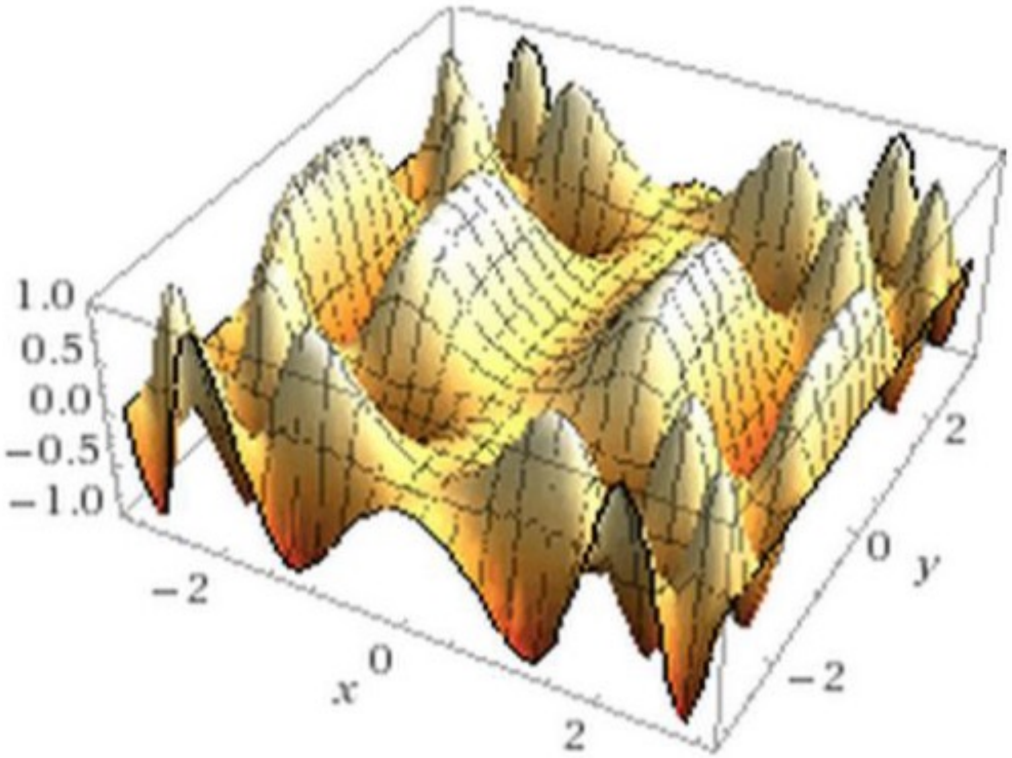
Weights



# Optimizer:

## Stochastic Gradient Descent (SGD)

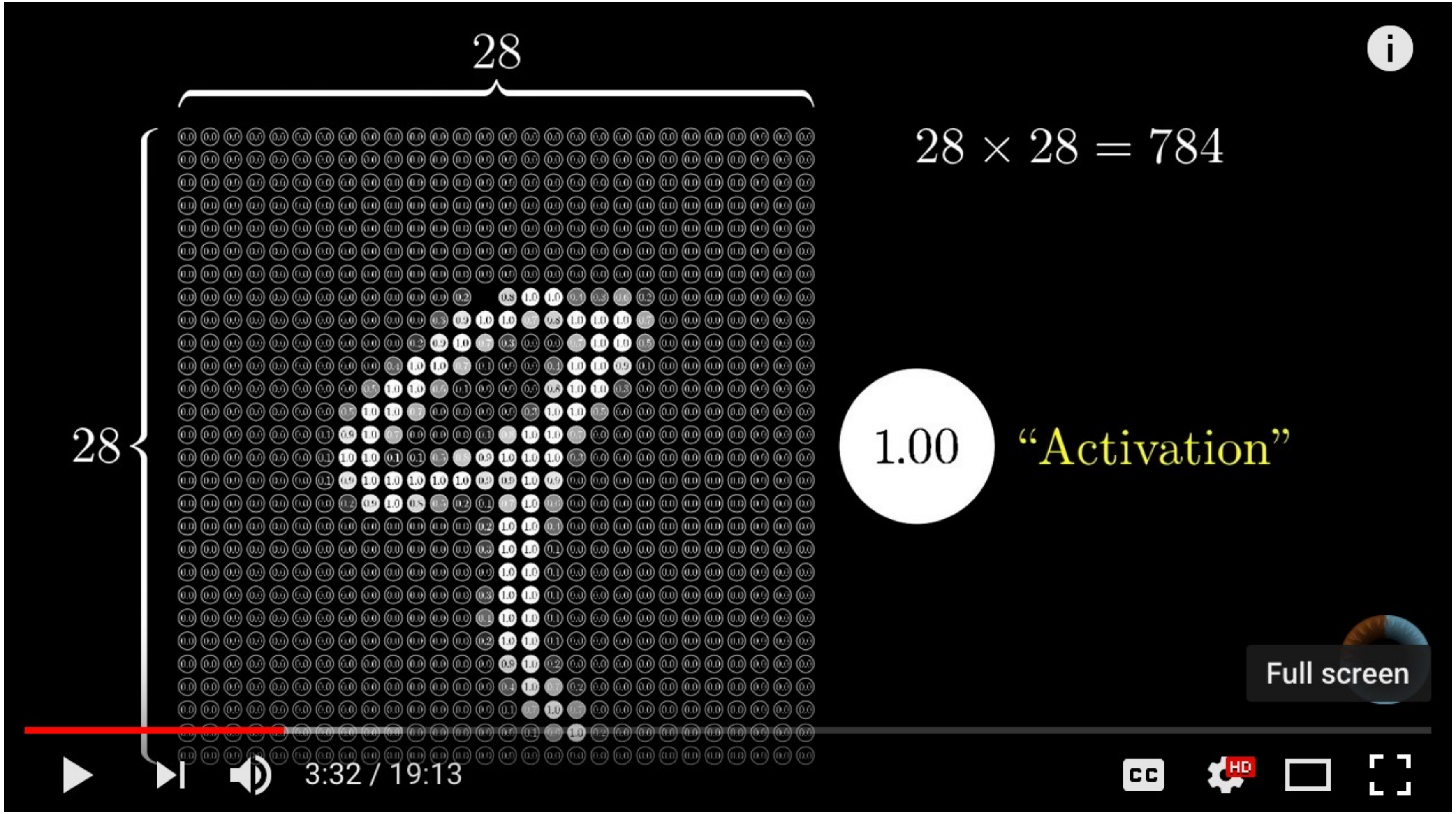





*This shows a function of 2 variables: real neural nets are functions of hundreds of millions of variables!*

Source: Jeff Dean (2016), Large-Scale Deep Learning For Building Intelligent Computer Systems, WSDM 2016

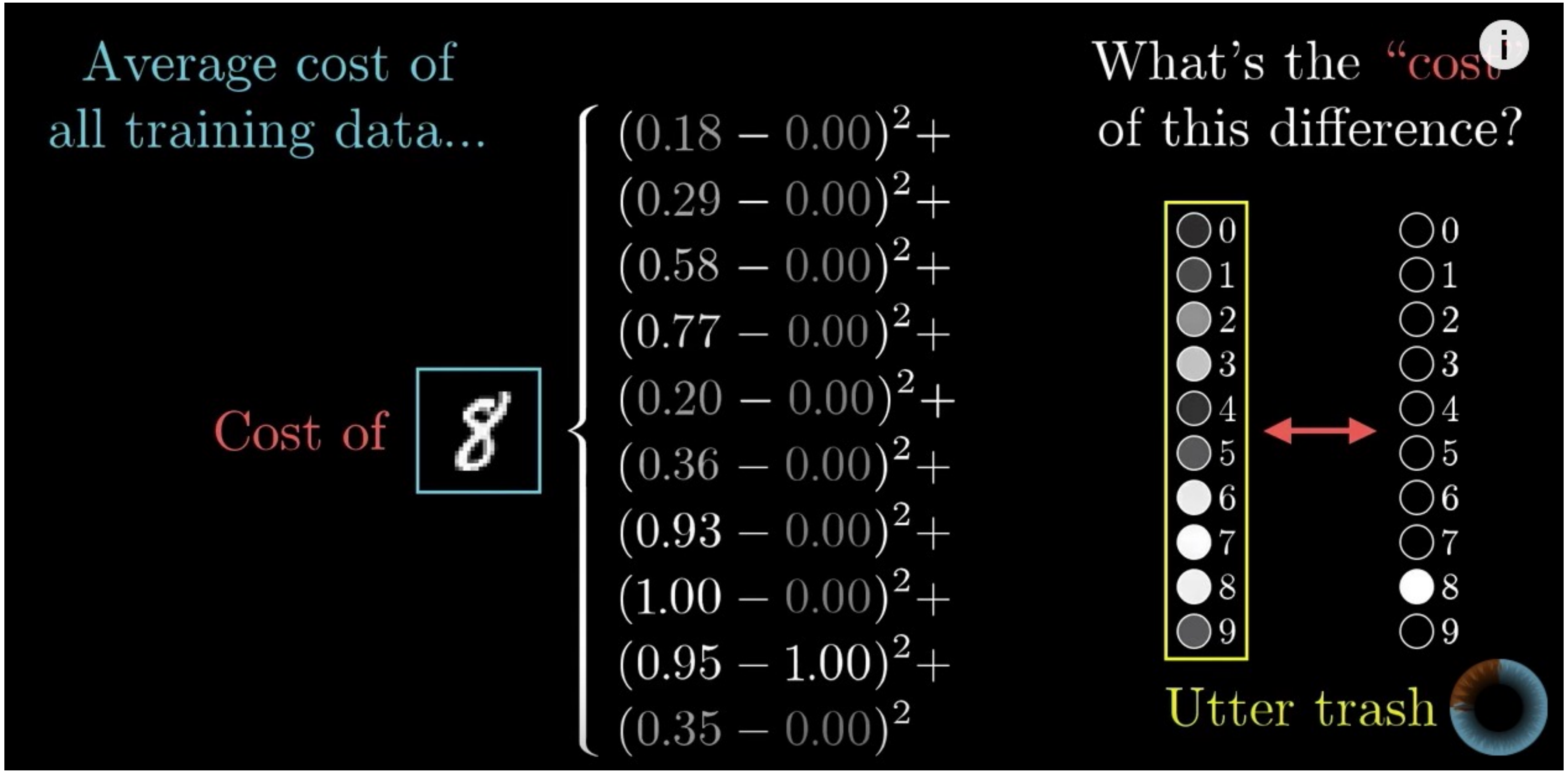
# Neural Network and Deep Learning




Source: 3Blue1Brown (2017), But what *is* a Neural Network? | Chapter 1, deep learning,
https://www.youtube.com/watch?v=aircAruvnKk

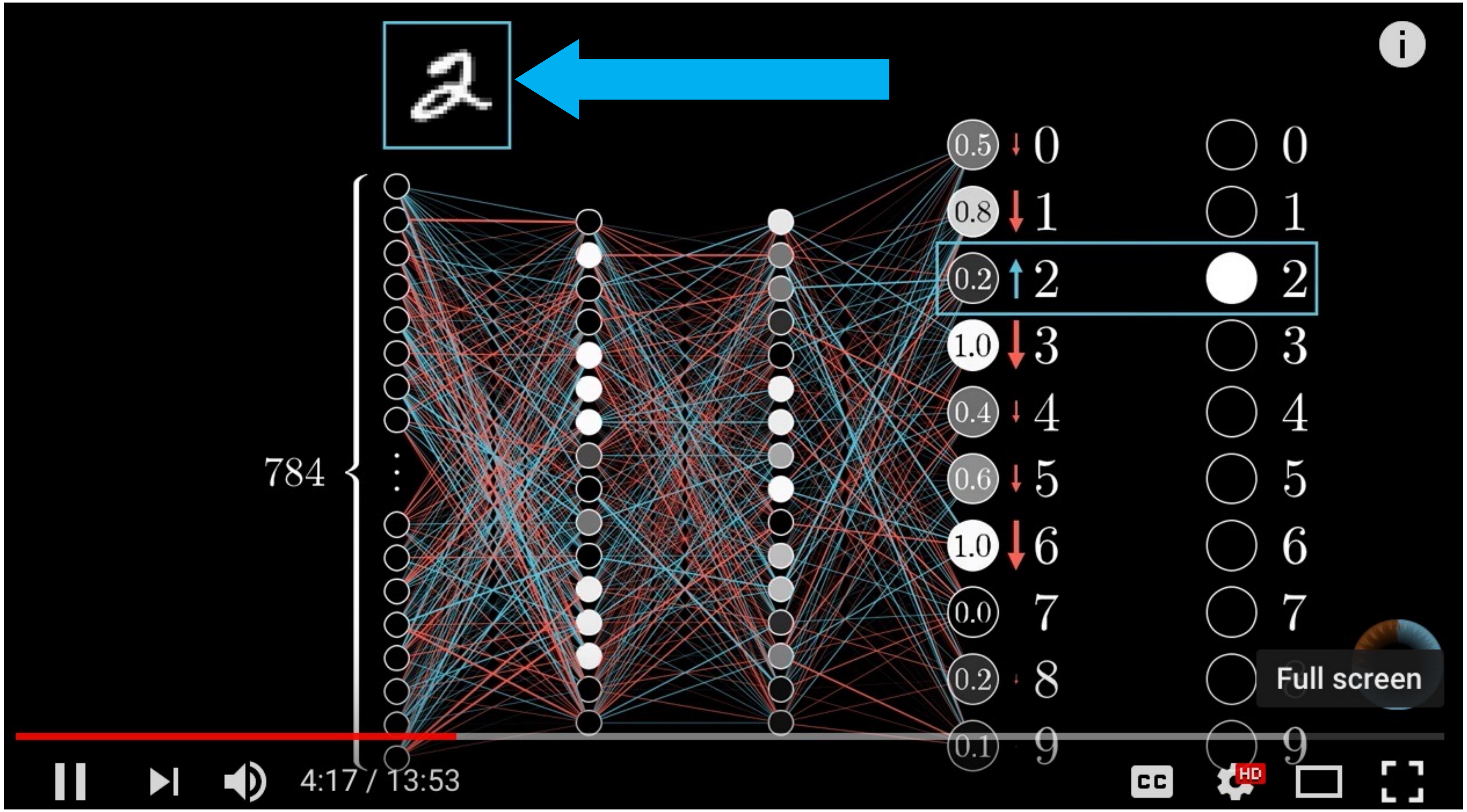
# Gradient Descent

## how neural networks learn




Source: 3Blue1Brown (2017), Gradient descent, how neural networks learn | Chapter 2, deep learning, https://www.youtube.com/watch?v=IHZwWFHWa-w

# Backpropagation




Source: 3Blue1Brown (2017), What is backpropagation really doing? | Chapter 3, deep learning, https://www.youtube.com/watch?v=Ilg3gGewQ5U

# Learning Algorithm

**While not done:**

**Pick a random training example "(input, label)"**

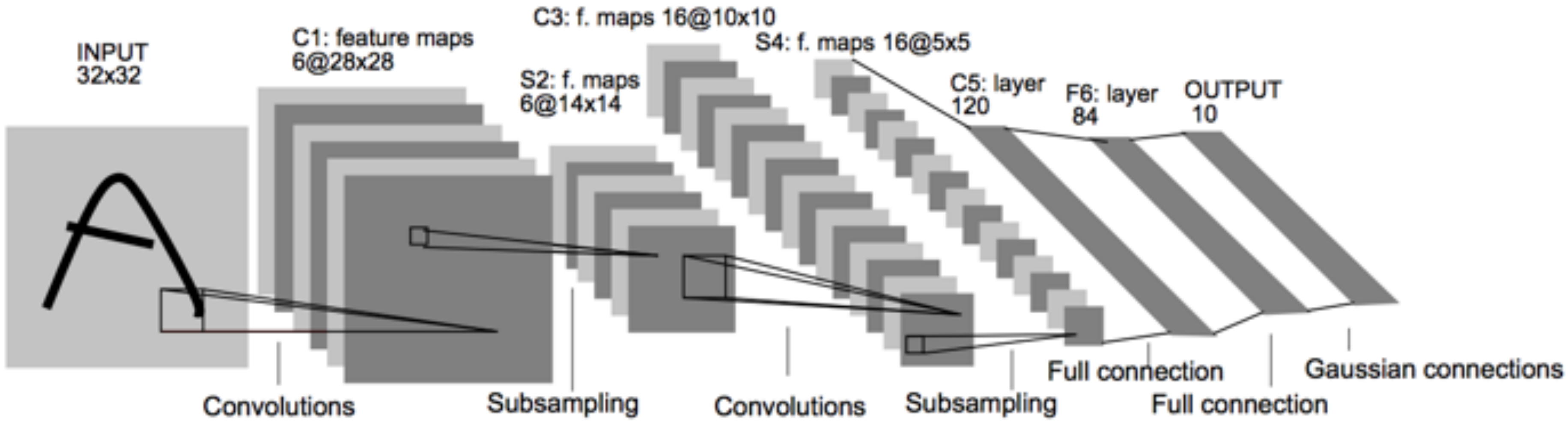
**Run neural network on "input"**

**Adjust weights on edges to make output closer to "label"**

Source: Jeff Dean (2016), Large-Scale Deep Learning For Building Intelligent Computer Systems, WSDM 2016

# Convolutional Neural Networks (CNN)

# Convolutional Neural Networks (CNN)




## Architecture of LeNet-5 (7 Layers) (LeCun et al., 1998)

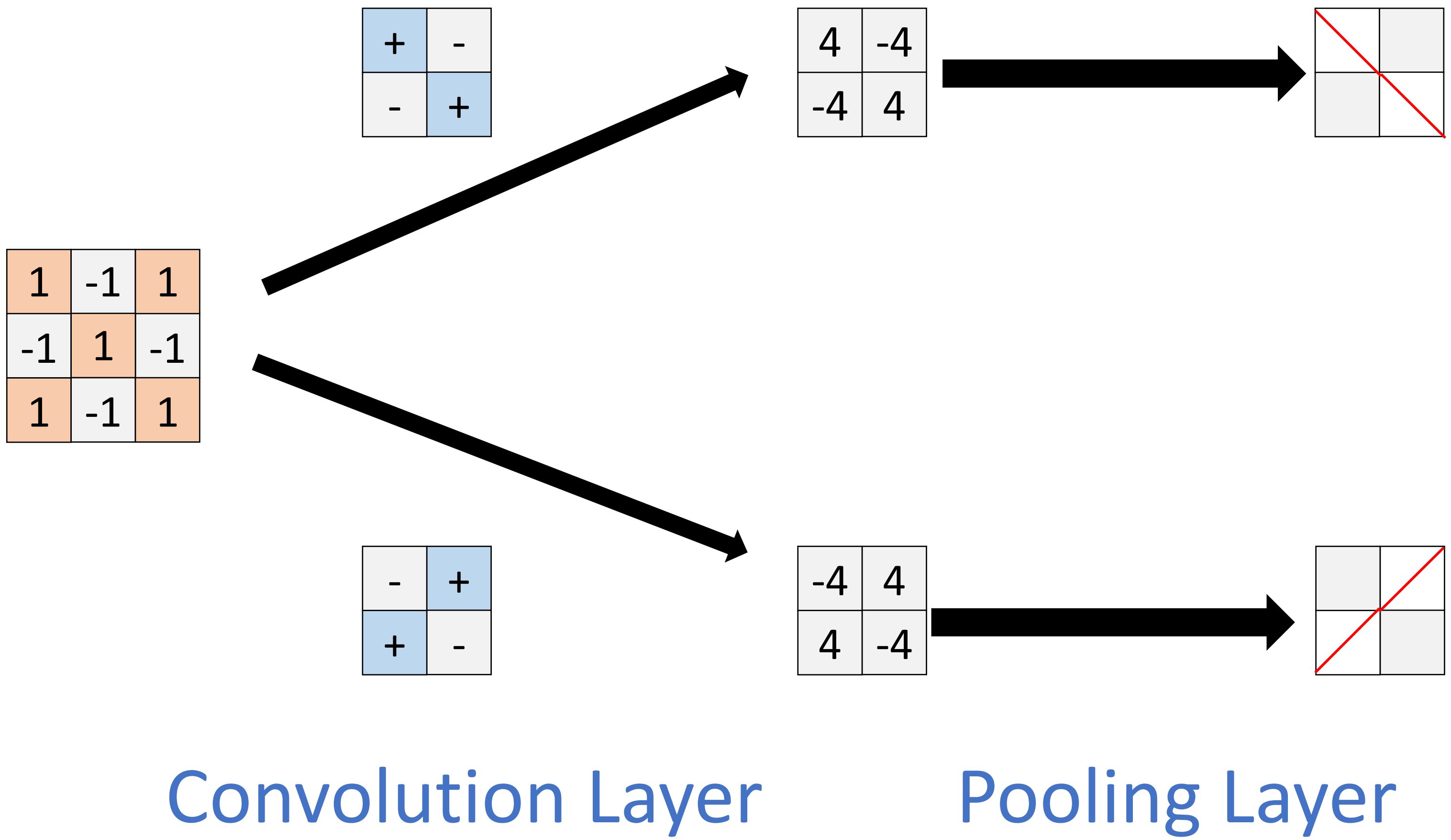
Source: http://yann.lecun.com/exdb/publis/pdf/lecun-01a.pdf

Source: LeCun, Yann, Léon Bottou, Yoshua Bengio, and Patrick Haffner.
"Gradient-based learning applied to document recognition." *Proceedings of the IEEE* 86, no. 11 (1998): 2278-2324.

# Convolutional Neural Networks (CNN)

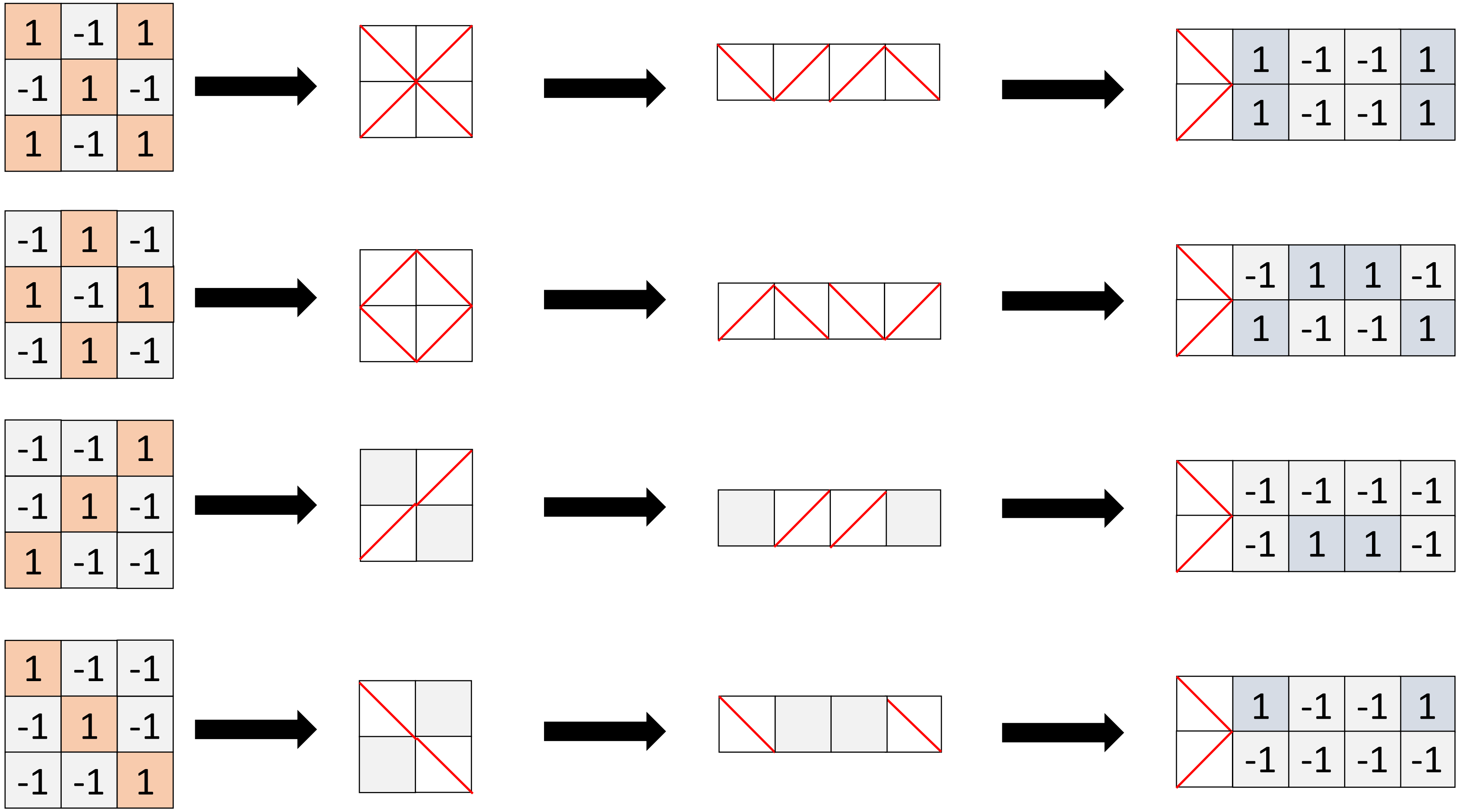
- **Convolution**
- **Pooling**
- **Fully Connection (FC) (Flattening)**

# A friendly introduction to Convolutional Neural Networks and Image Recognition



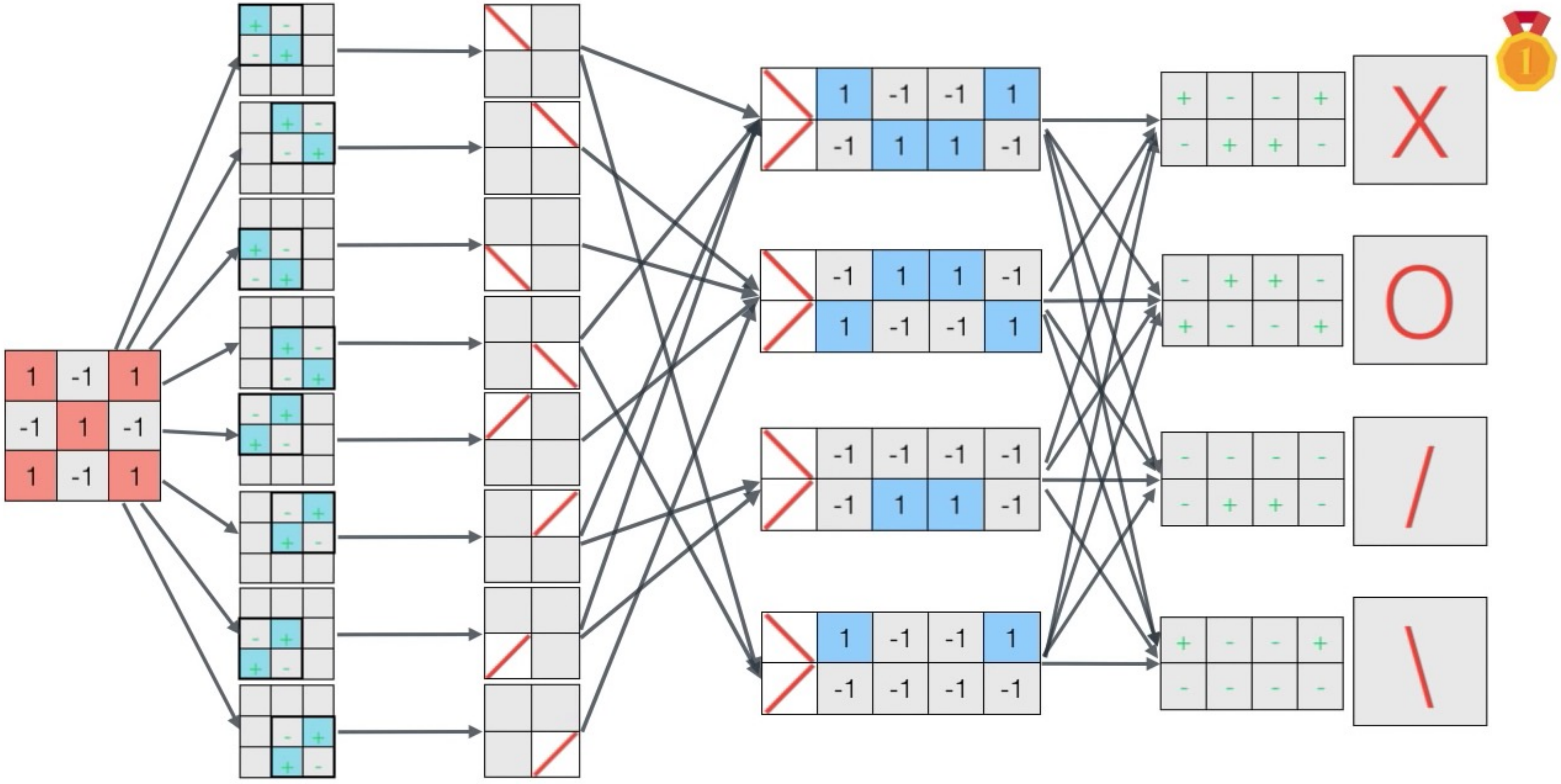

Source: Luis Serrano (2017), A friendly introduction to Convolutional Neural Networks and Image Recognition, https://www.youtube.com/watch?v=2-Ol7ZB0MmU

# A friendly introduction to Convolutional Neural Networks and Image Recognition



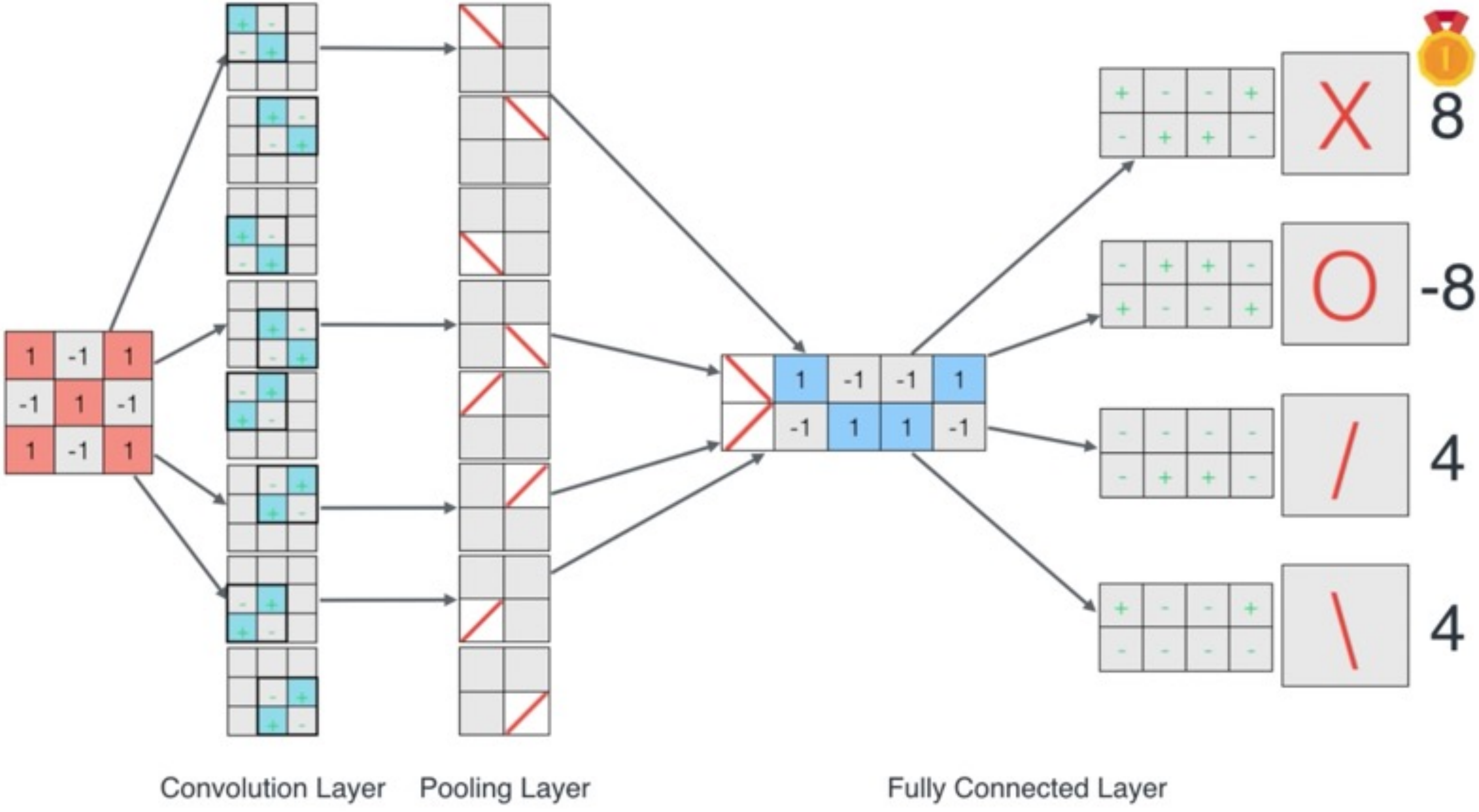

Source: Luis Serrano (2017), A friendly introduction to Convolutional Neural Networks and Image Recognition, https://www.youtube.com/watch?v=2-Ol7ZB0MmU

# A friendly introduction to Convolutional Neural Networks and Image Recognition



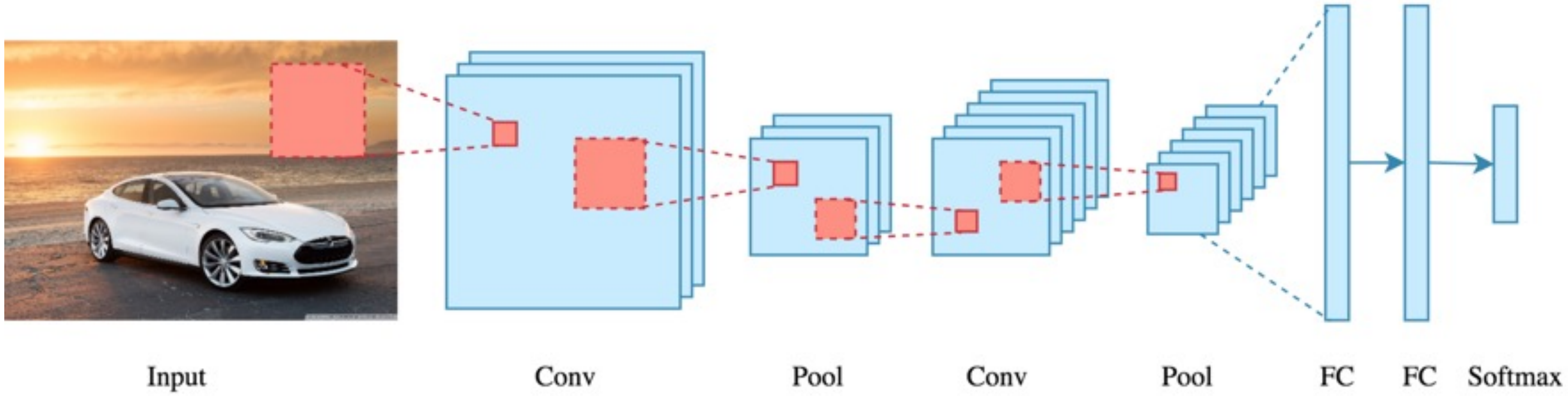

Source: Luis Serrano (2017), A friendly introduction to Convolutional Neural Networks and Image Recognition, https://www.youtube.com/watch?v=2-Ol7ZB0MmU

# A friendly introduction to Convolutional Neural Networks and Image Recognition




Source: Luis Serrano (2017), A friendly introduction to Convolutional Neural Networks and Image Recognition, https://www.youtube.com/watch?v=2-Ol7ZB0MmU

# CNN Architecture




Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer

**Convolution** is a **mathematical operation** to **merge two sets** of information

3x3 convolution

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

Input

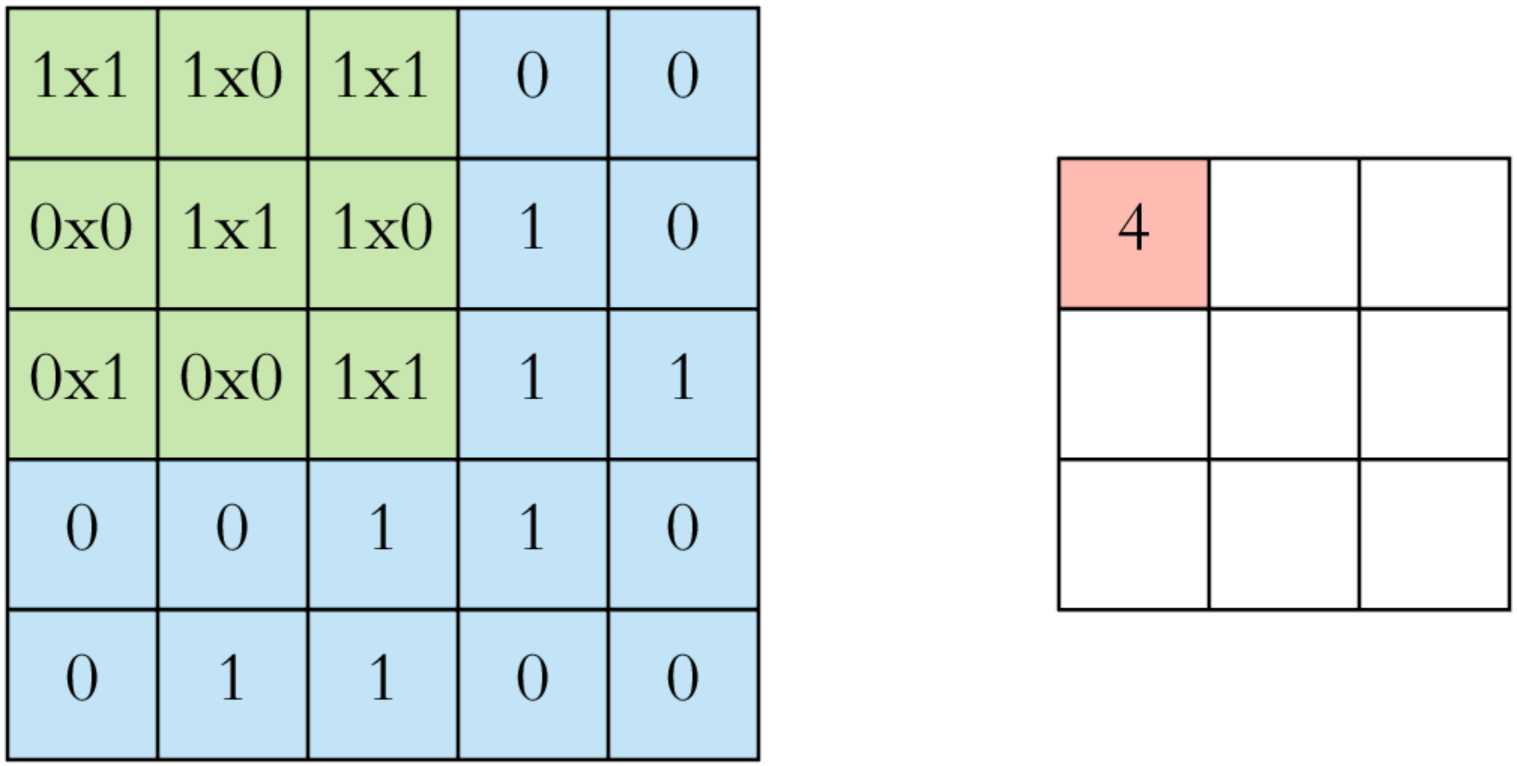
| | | |
|---|---|---|
| 1 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 1 |

Filter / Kernel

Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer
# Input x Filter --> Feature Map

receptive field: 3x3



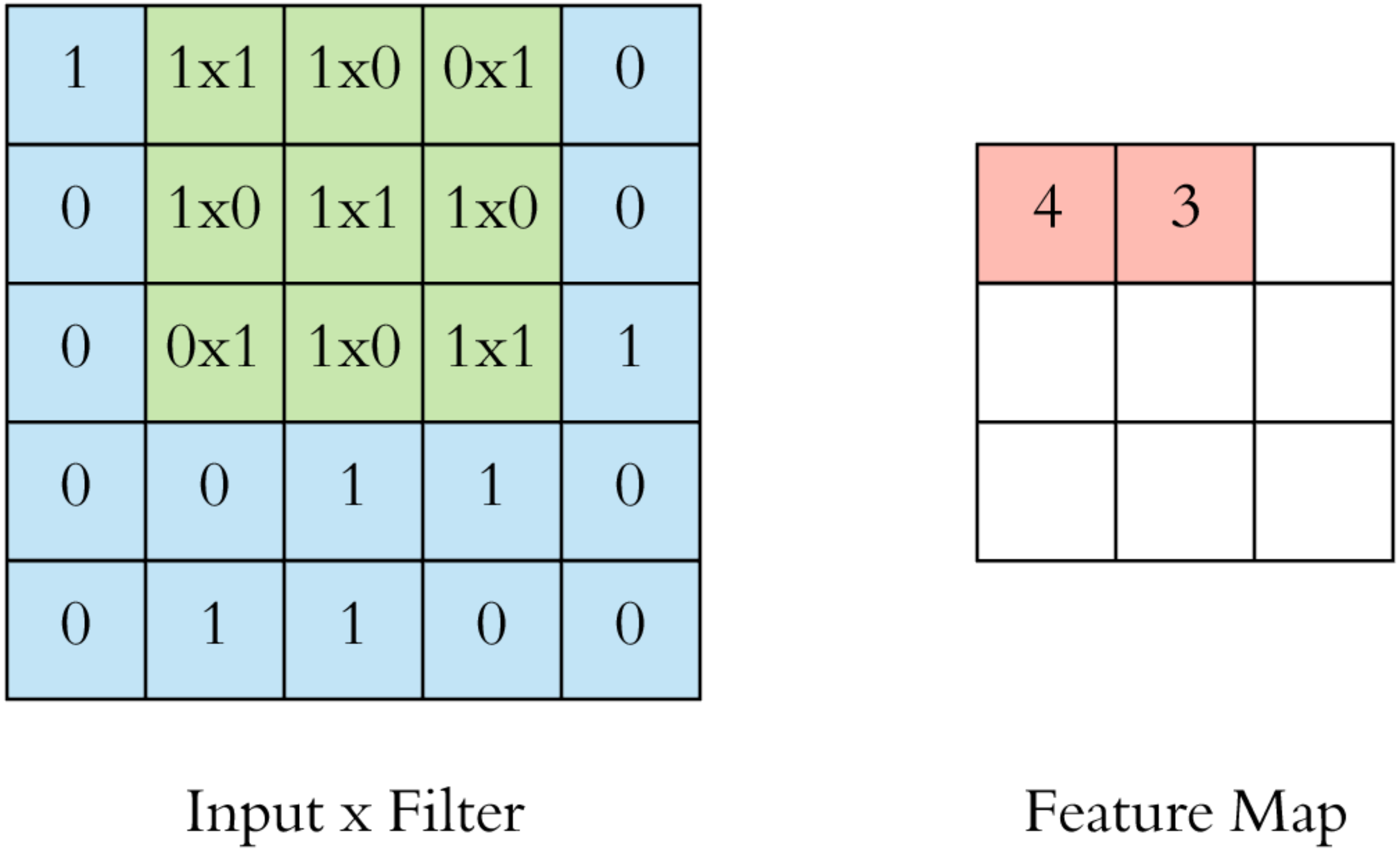

Input x Filter

Feature Map

Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

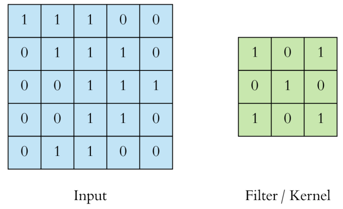
# CNN Convolution Layer
# Input x Filter --> Feature Map

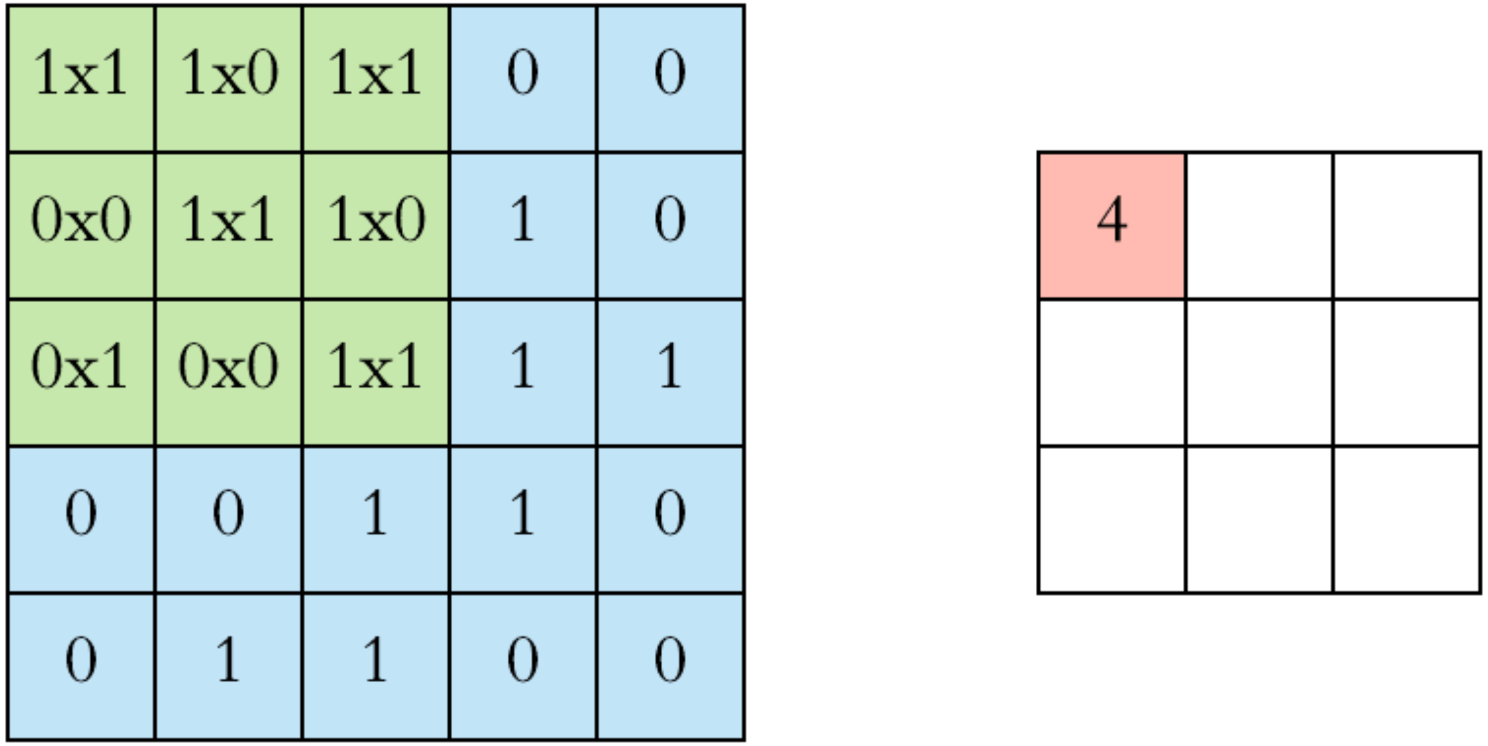
receptive field: 3x3




Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer



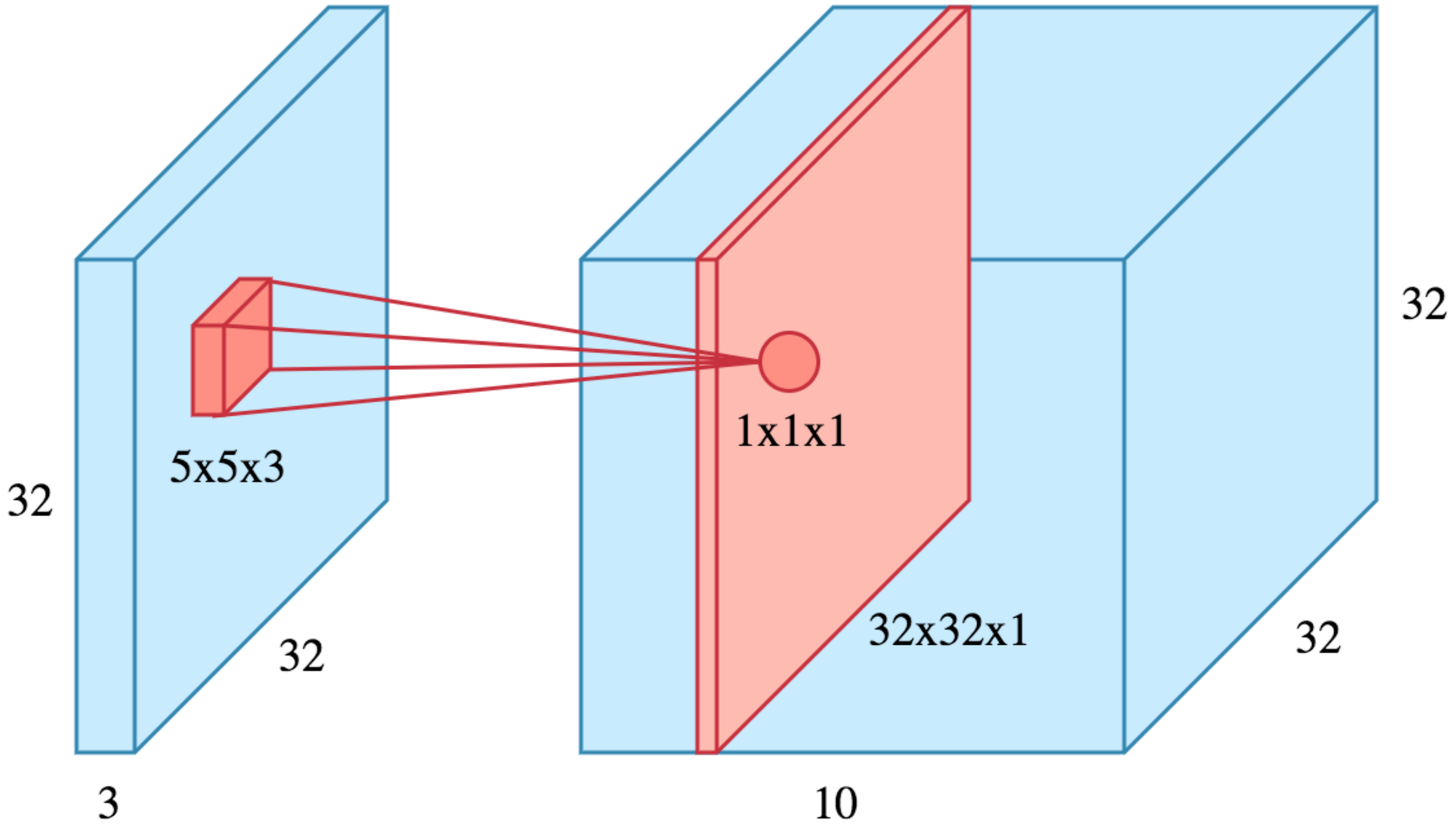

Example convolution operation shown in 2D using a 3x3 filter

Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks, https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer

10 different filters

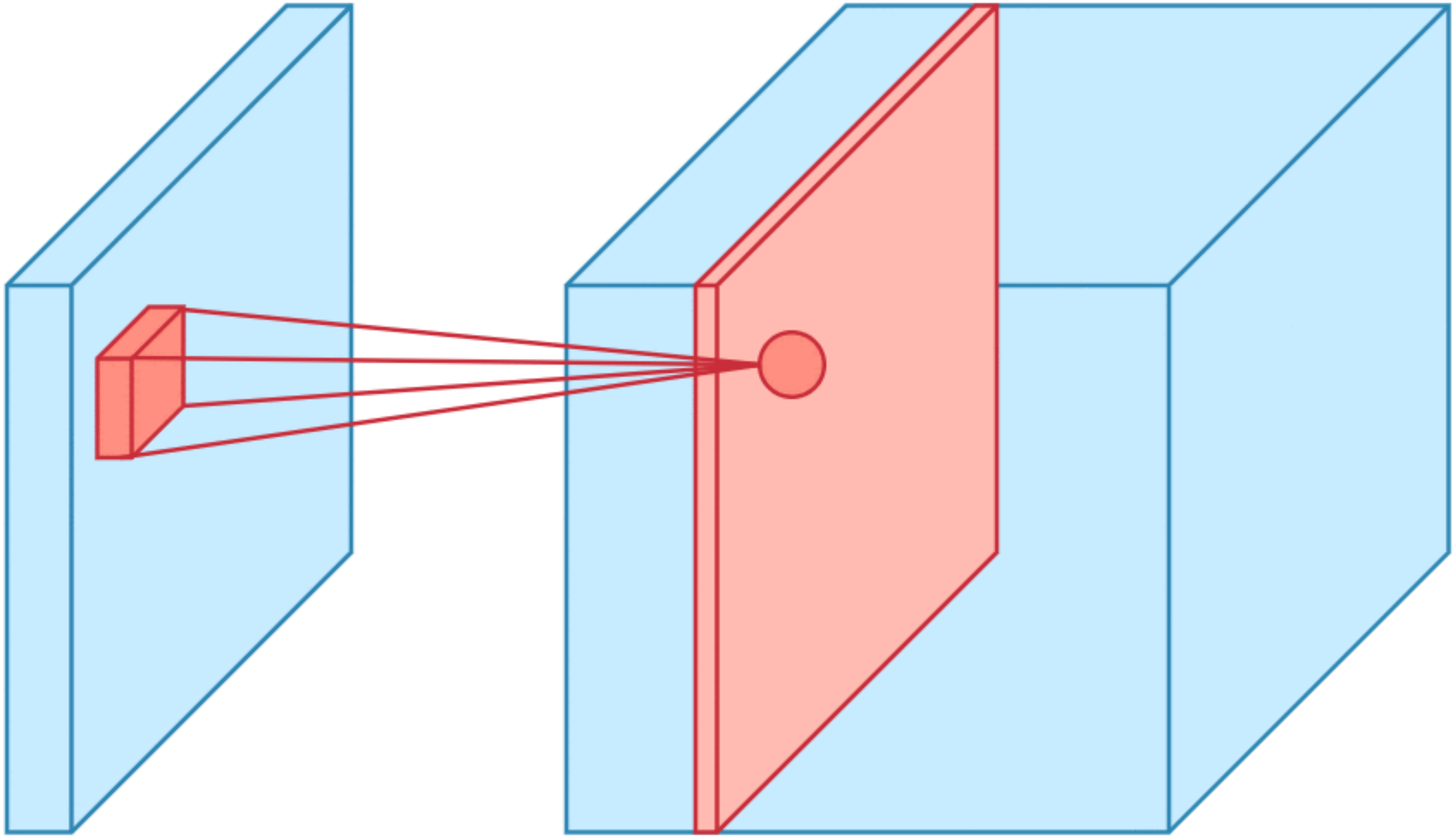
10 feature maps of size 32x32x1




final output of the convolution layer:
a volume of size 32x32x10

Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

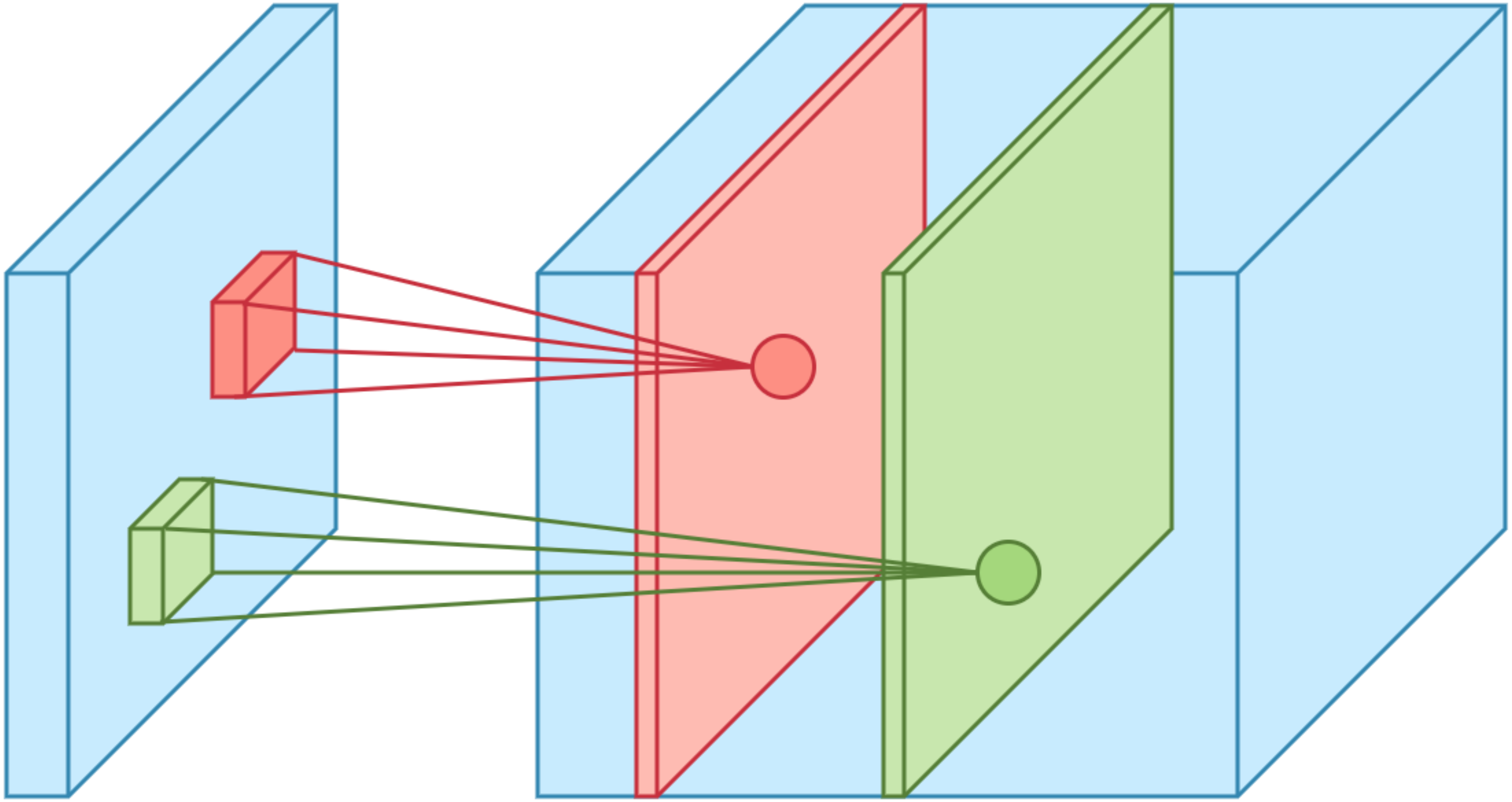
# CNN Convolution Layer
## Sliding operation at 4 locations



Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer

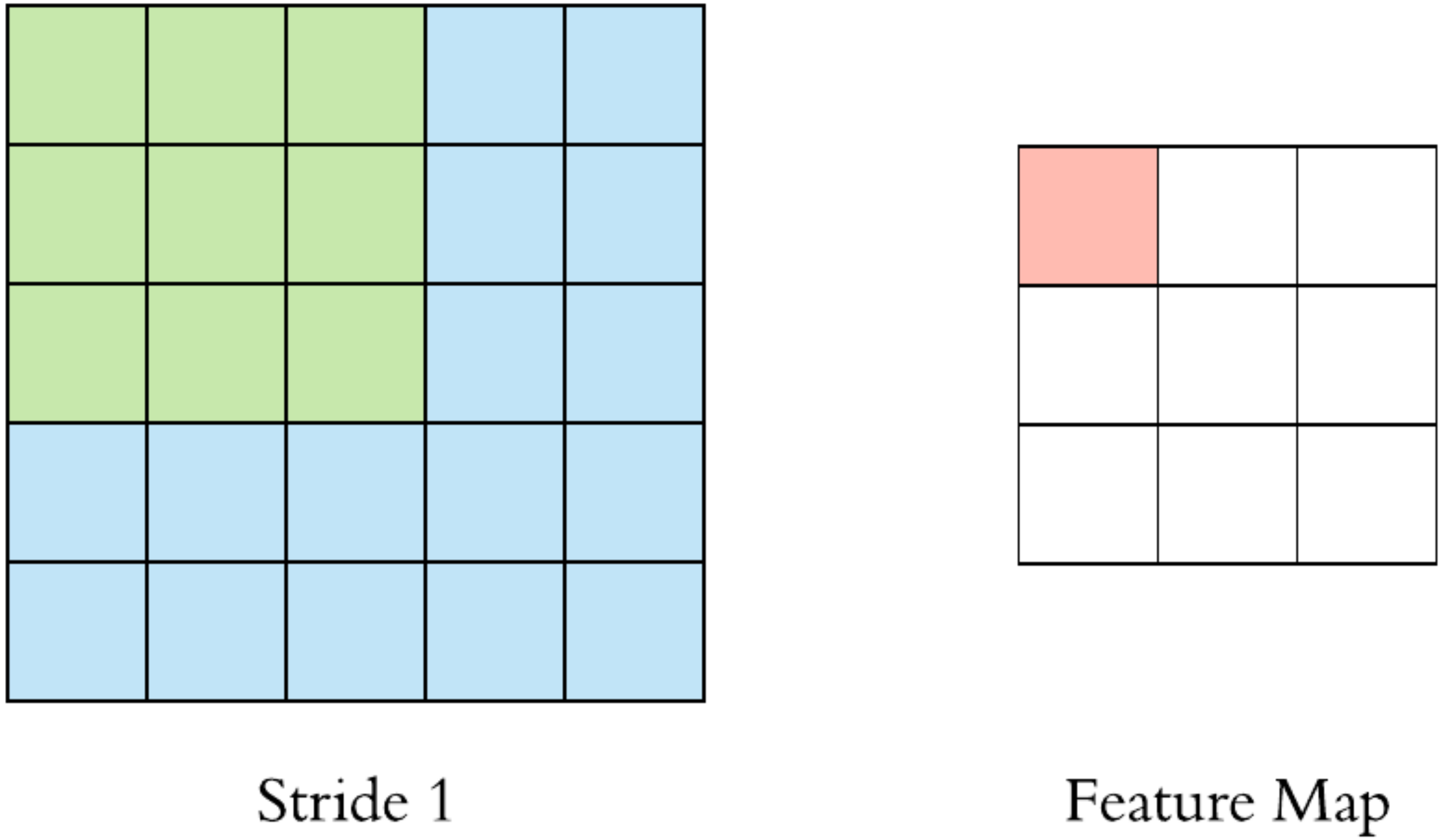
two feature maps



Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer

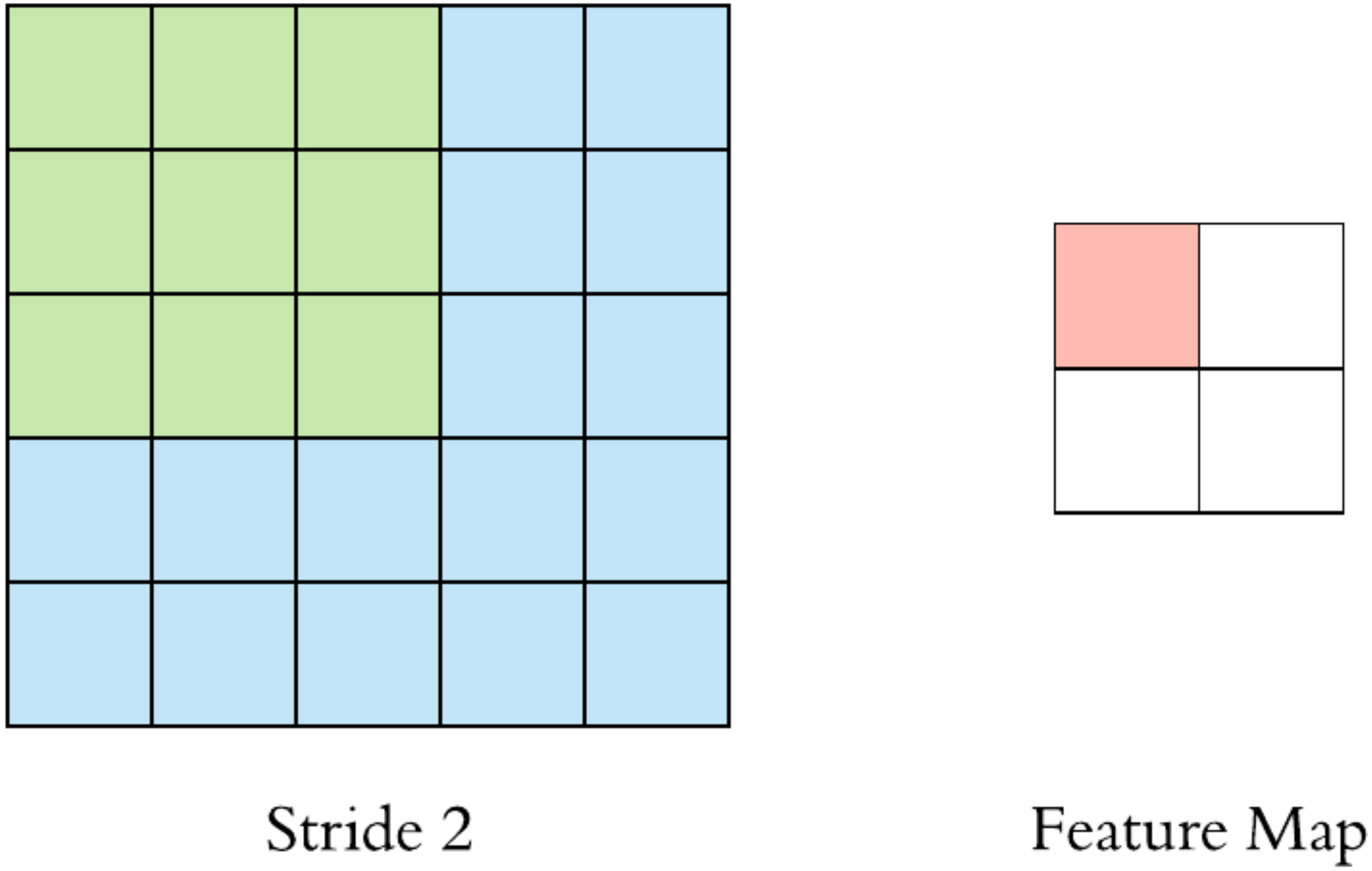
**Stride** specifies how much
we move the convolution filter at each step




Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer

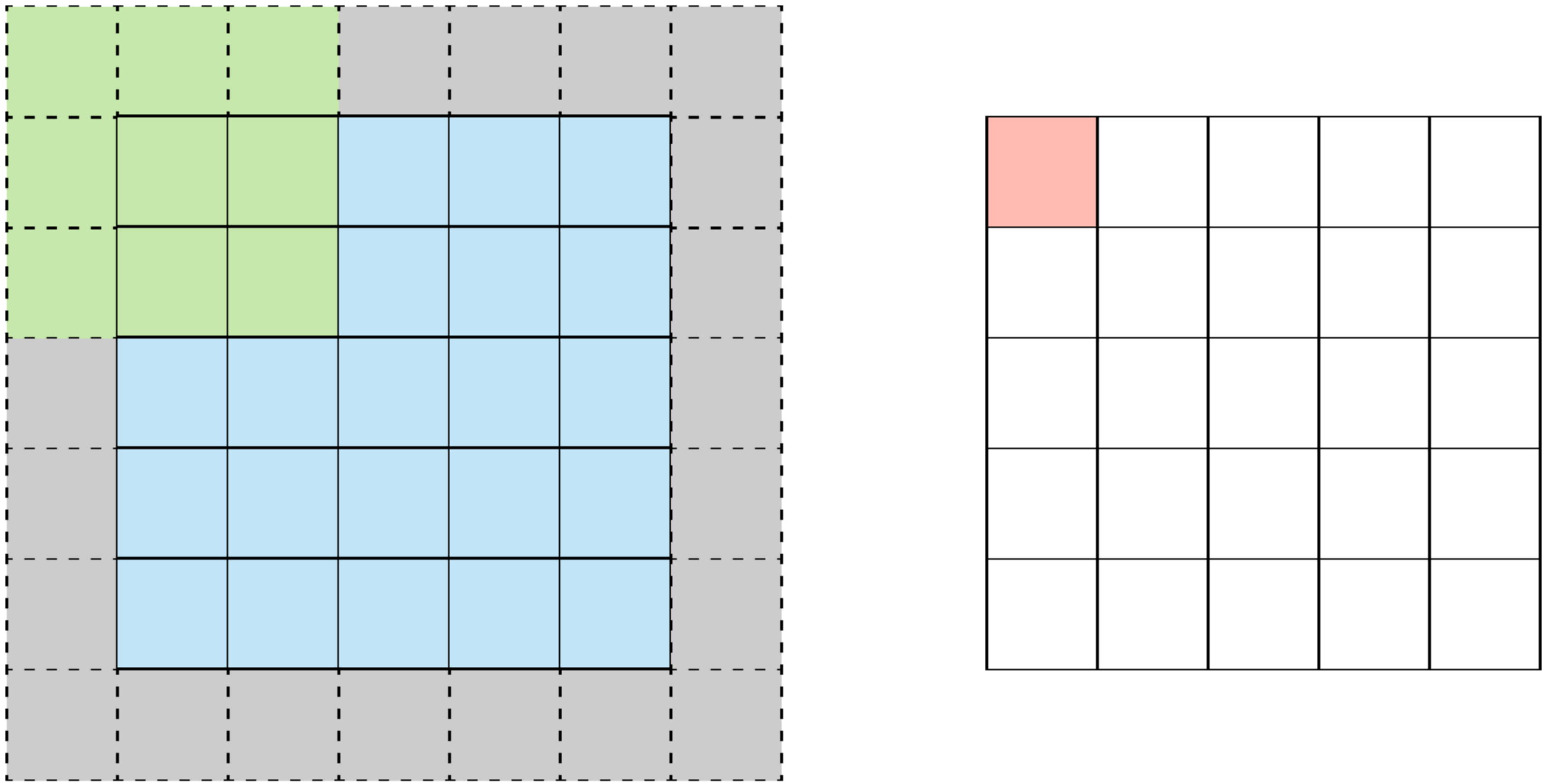
**Stride** specifies how much
we move the convolution filter at each step




Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Convolution Layer

## Stride 1 with Padding



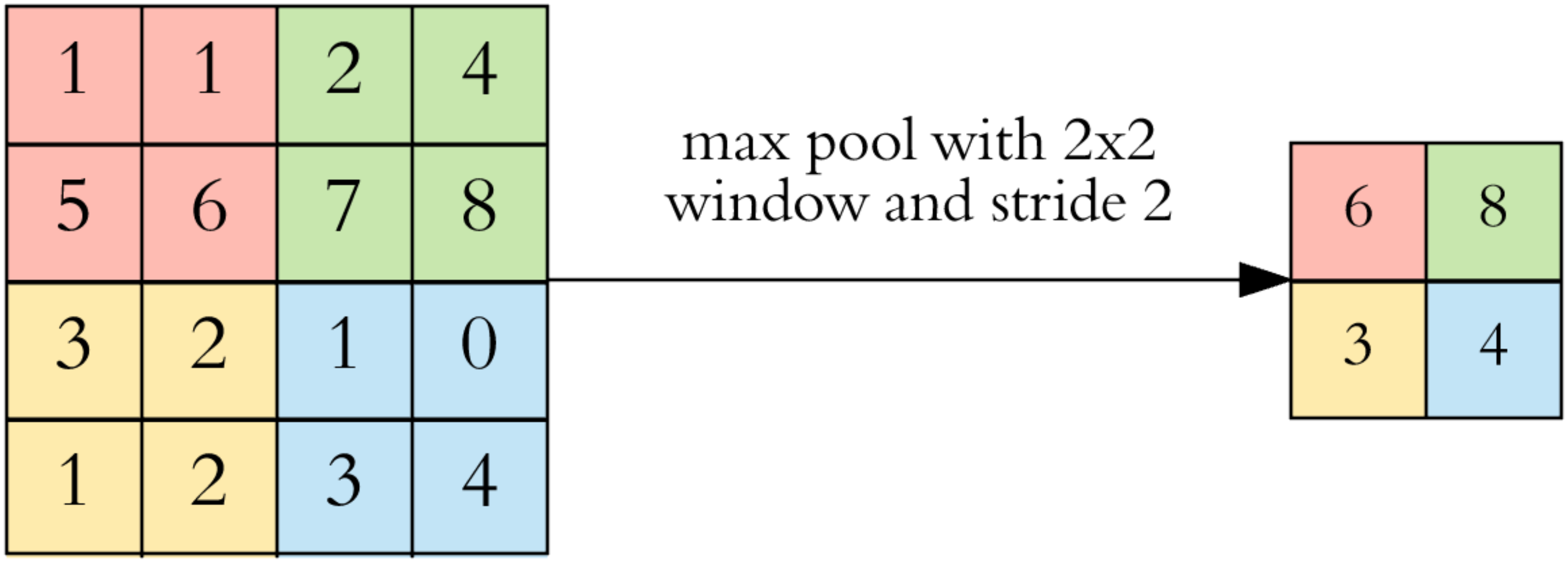
Stride 1 with Padding

Feature Map

Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks, https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

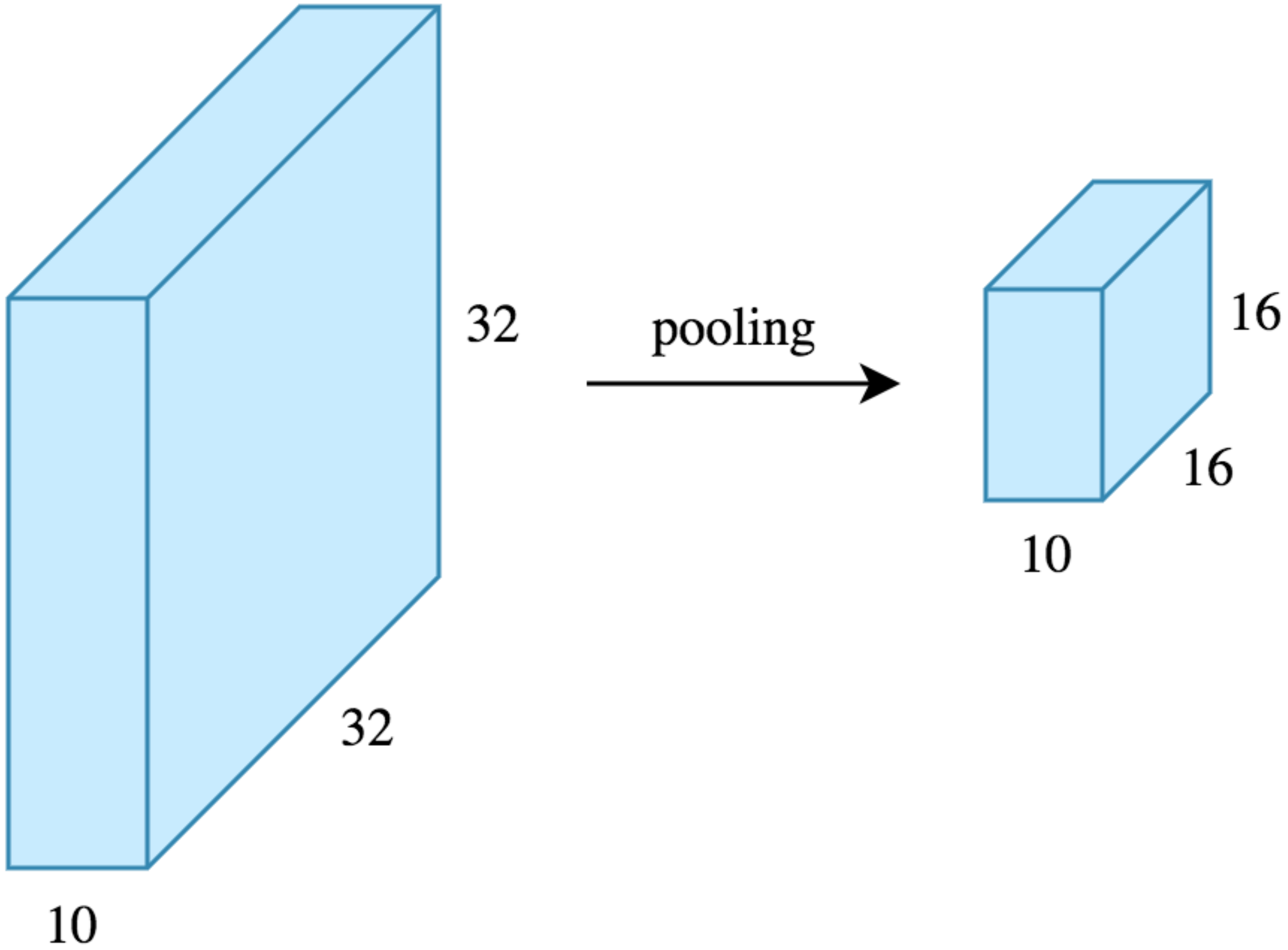
# CNN Pooling Layer

## Max Pooling



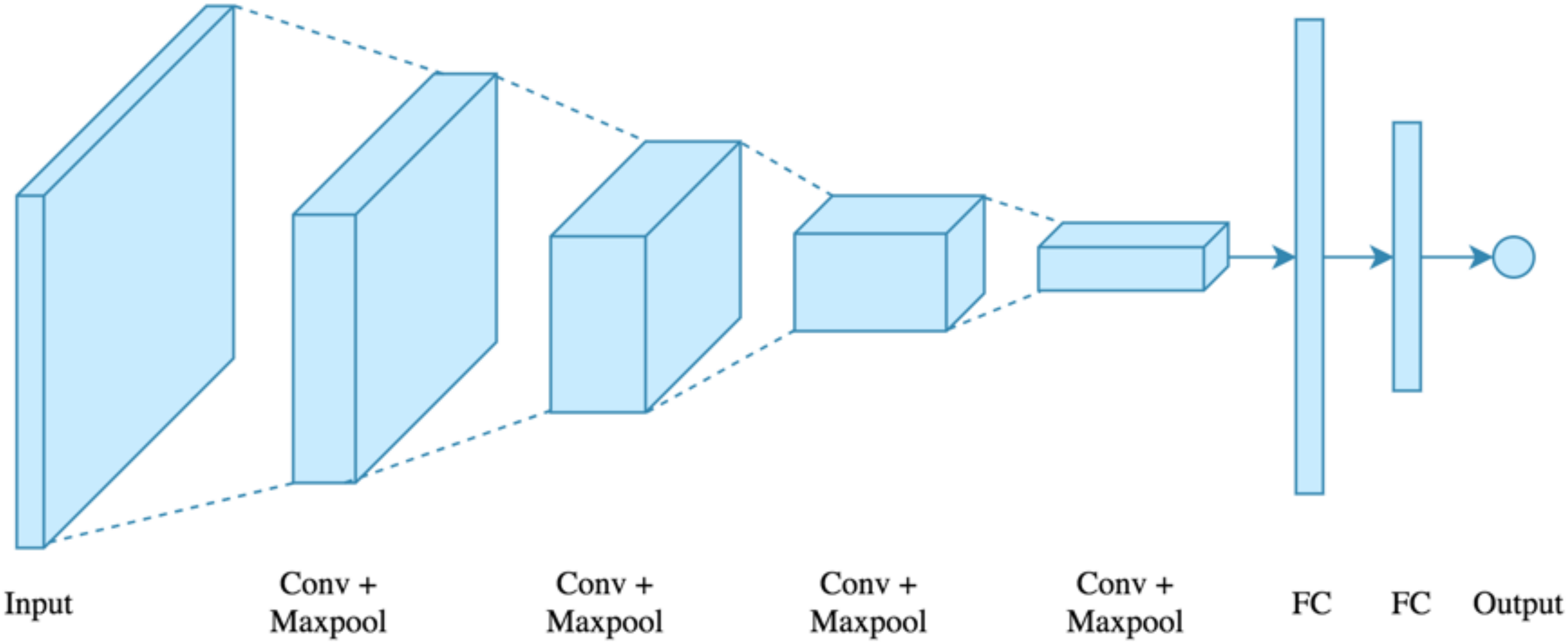

Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Pooling Layer




Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# CNN Architecture
# 4 convolution + pooling layers, followed by 2 fully connected layers




Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

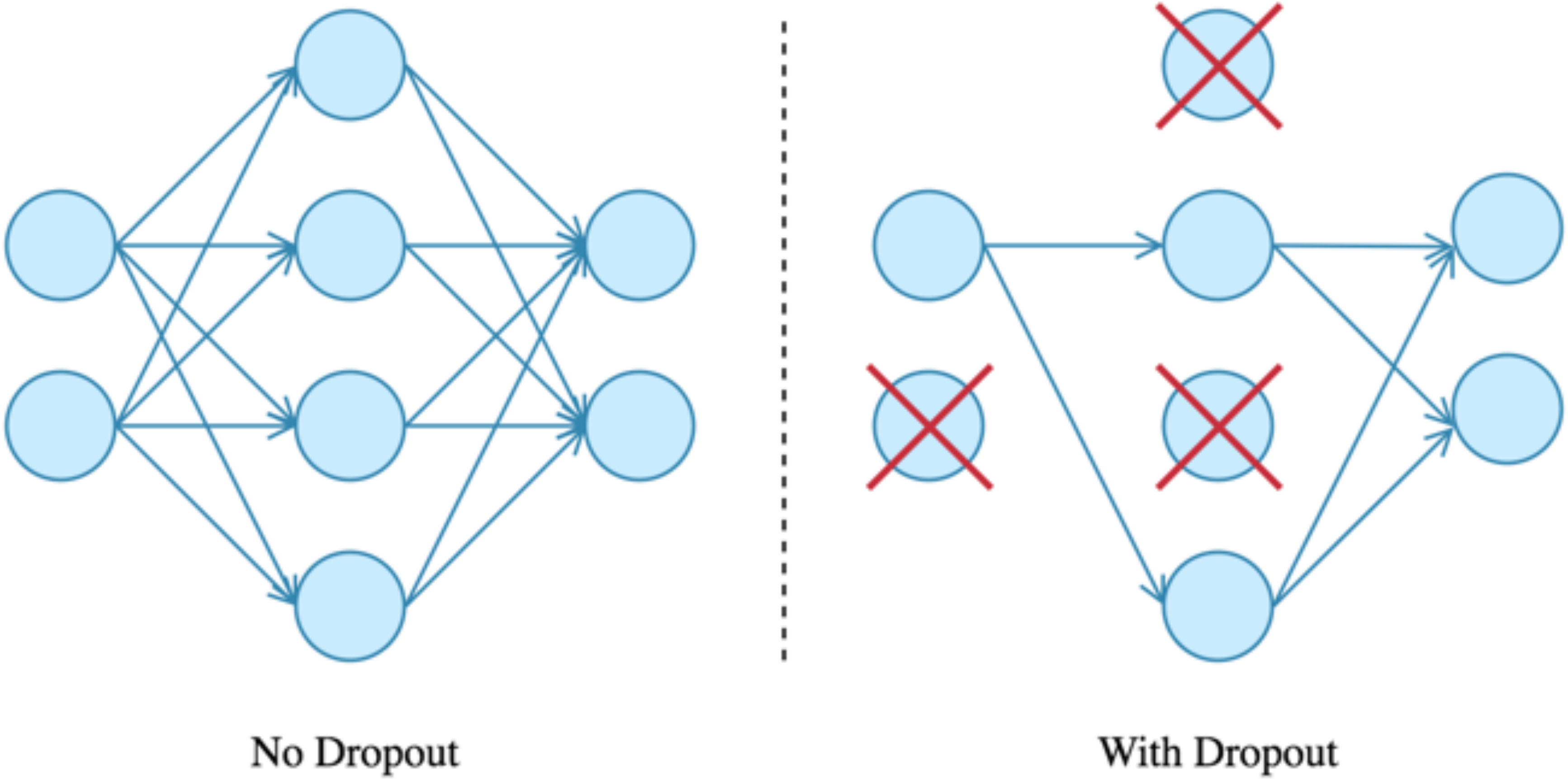
# CNN Architecture
# 4 convolution + pooling layers, followed by 2 fully connected layers

https://gist.github.com/ardendertat/0fc5515057c47e7386fe04e9334504e3

```
model = Sequential()
model.add(Conv2D(32, (3, 3), activation='relu', padding='same', name='conv_1',
                 input_shape=(150, 150, 3)))
model.add(MaxPooling2D((2, 2), name='maxpool_1'))
model.add(Conv2D(64, (3, 3), activation='relu', padding='same', name='conv_2'))
model.add(MaxPooling2D((2, 2), name='maxpool_2'))
model.add(Conv2D(128, (3, 3), activation='relu', padding='same', name='conv_3'))
model.add(MaxPooling2D((2, 2), name='maxpool_3'))
model.add(Conv2D(128, (3, 3), activation='relu', padding='same', name='conv_4'))
model.add(MaxPooling2D((2, 2), name='maxpool_4'))
model.add(Flatten())
model.add(Dropout(0.5))
model.add(Dense(512, activation='relu', name='dense_1'))
model.add(Dense(128, activation='relu', name='dense_2'))
model.add(Dense(1, activation='sigmoid', name='output'))
```

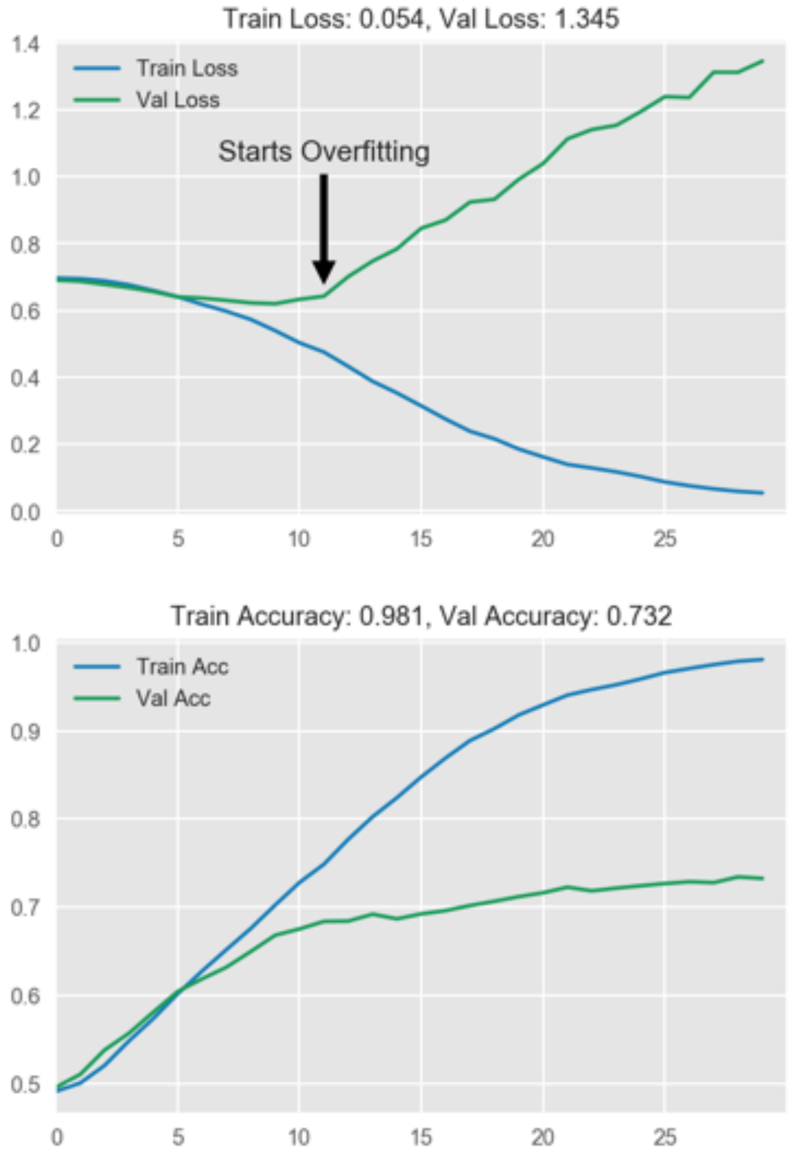
Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks,
https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# Dropout




Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks, https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

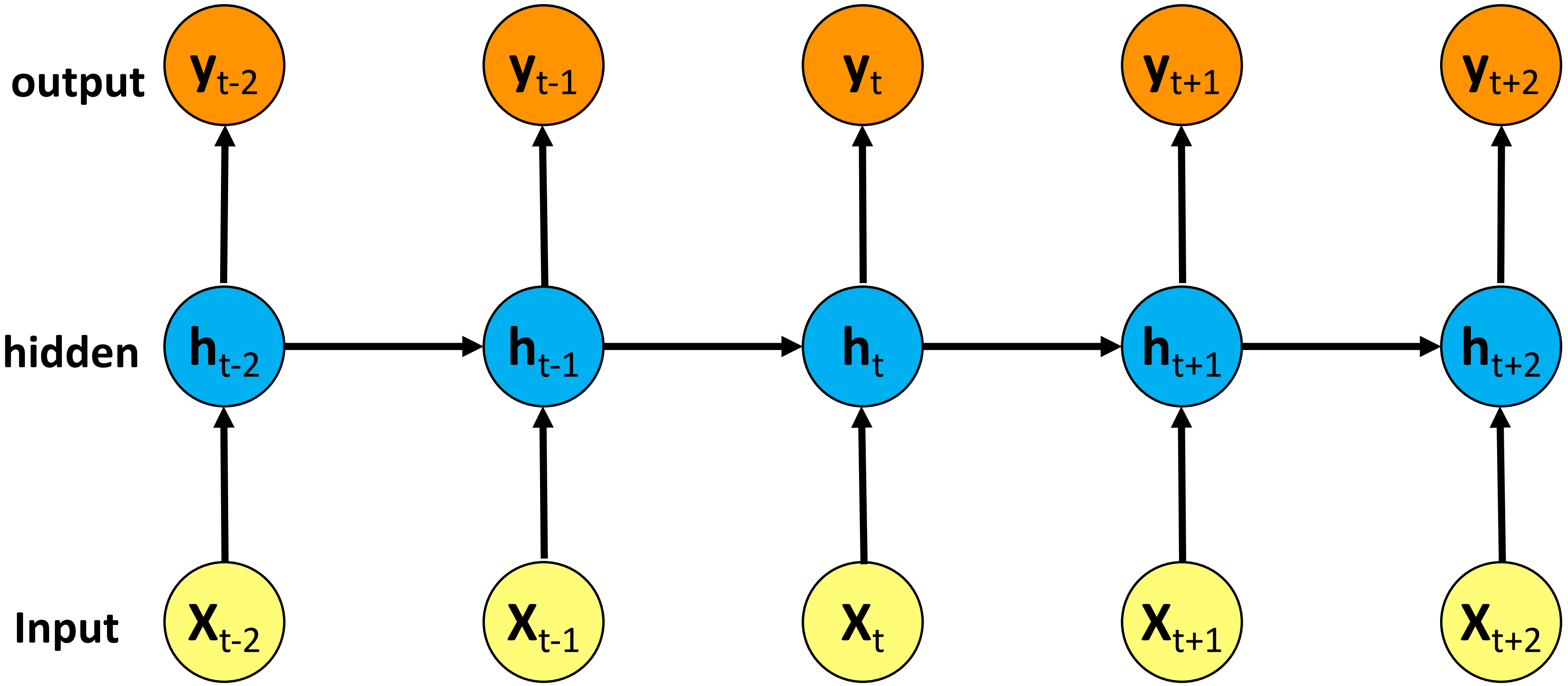
# Model Performance



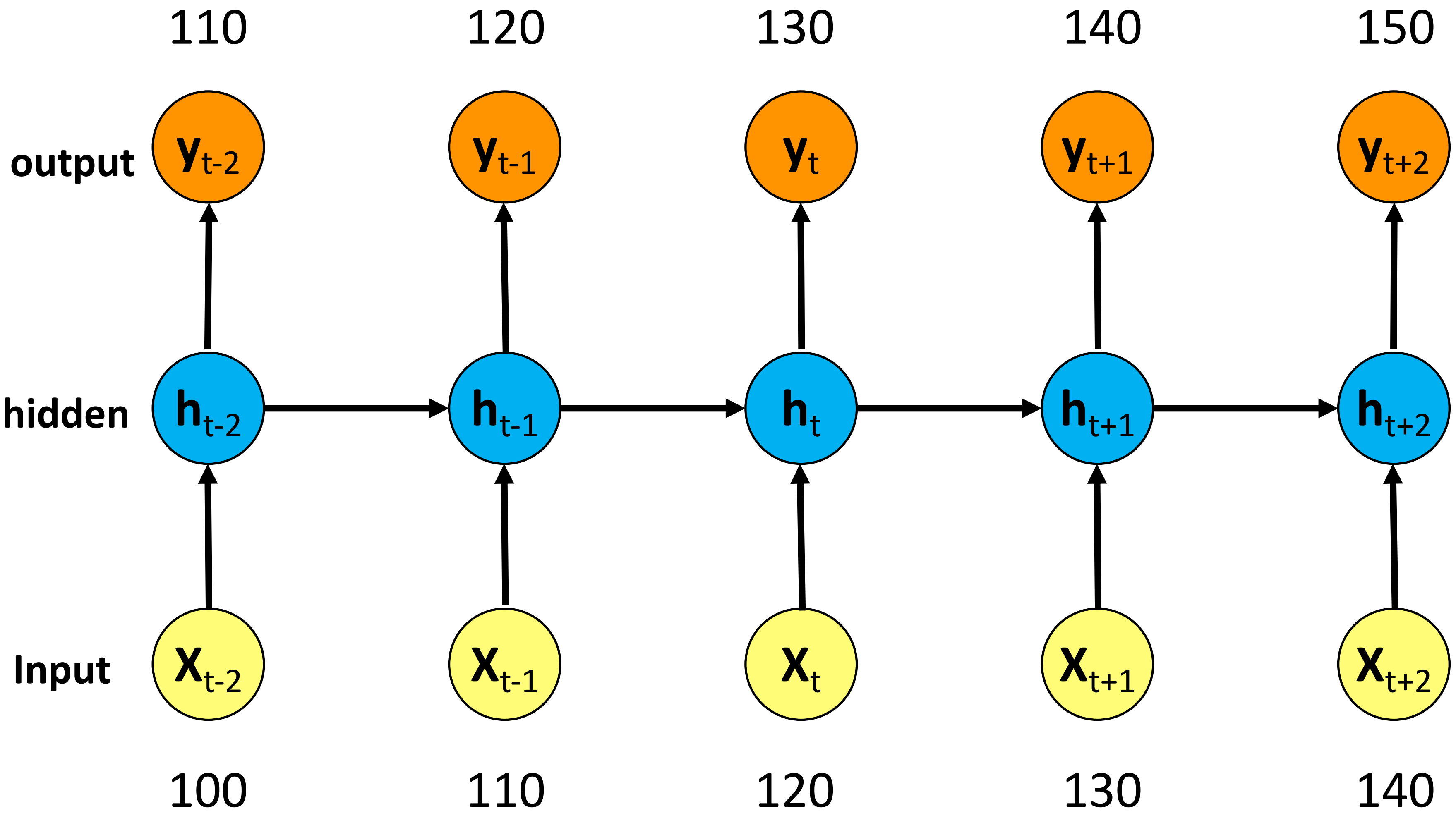

Source: Arden Dertat (2017), Applied Deep Learning - Part 4: Convolutional Neural Networks, https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2

# Recurrent Neural Networks (RNN)

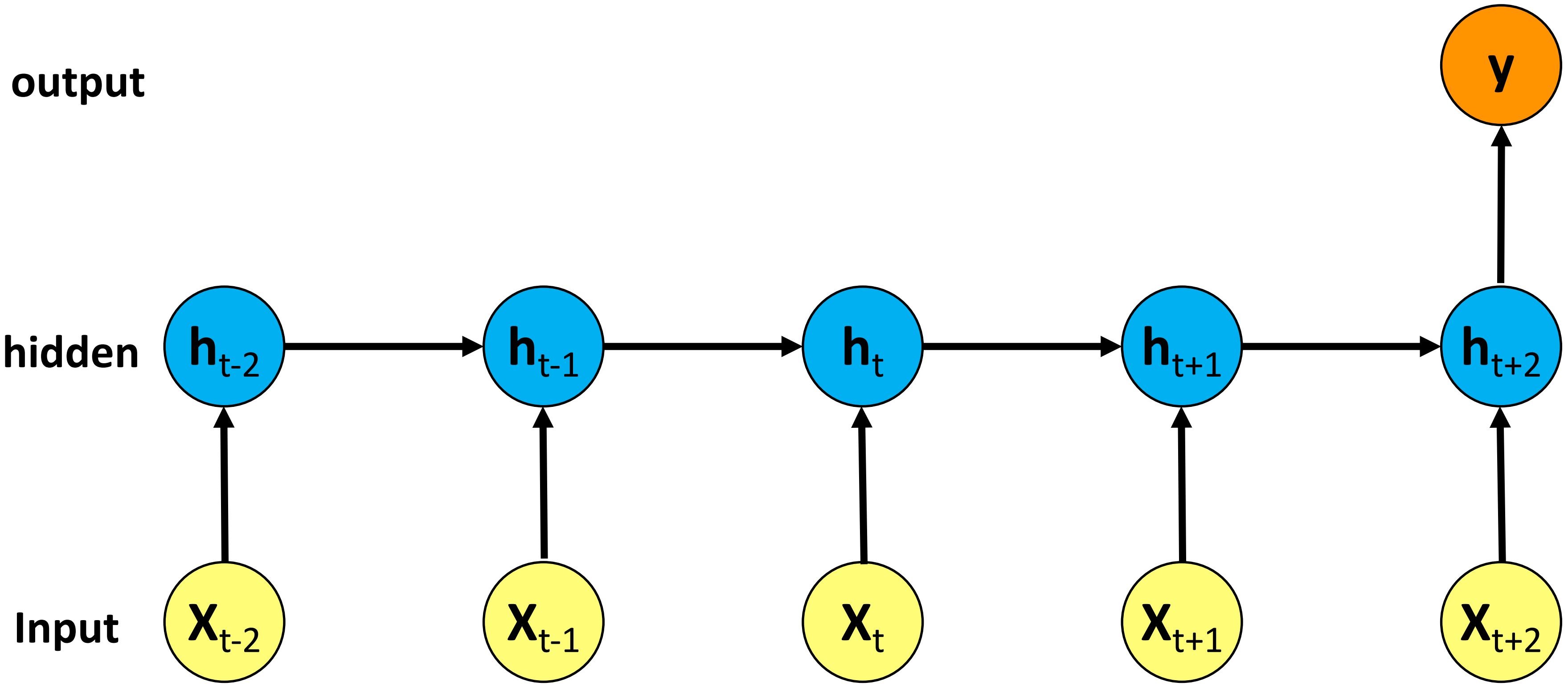
# Recurrent Neural Networks (RNN)



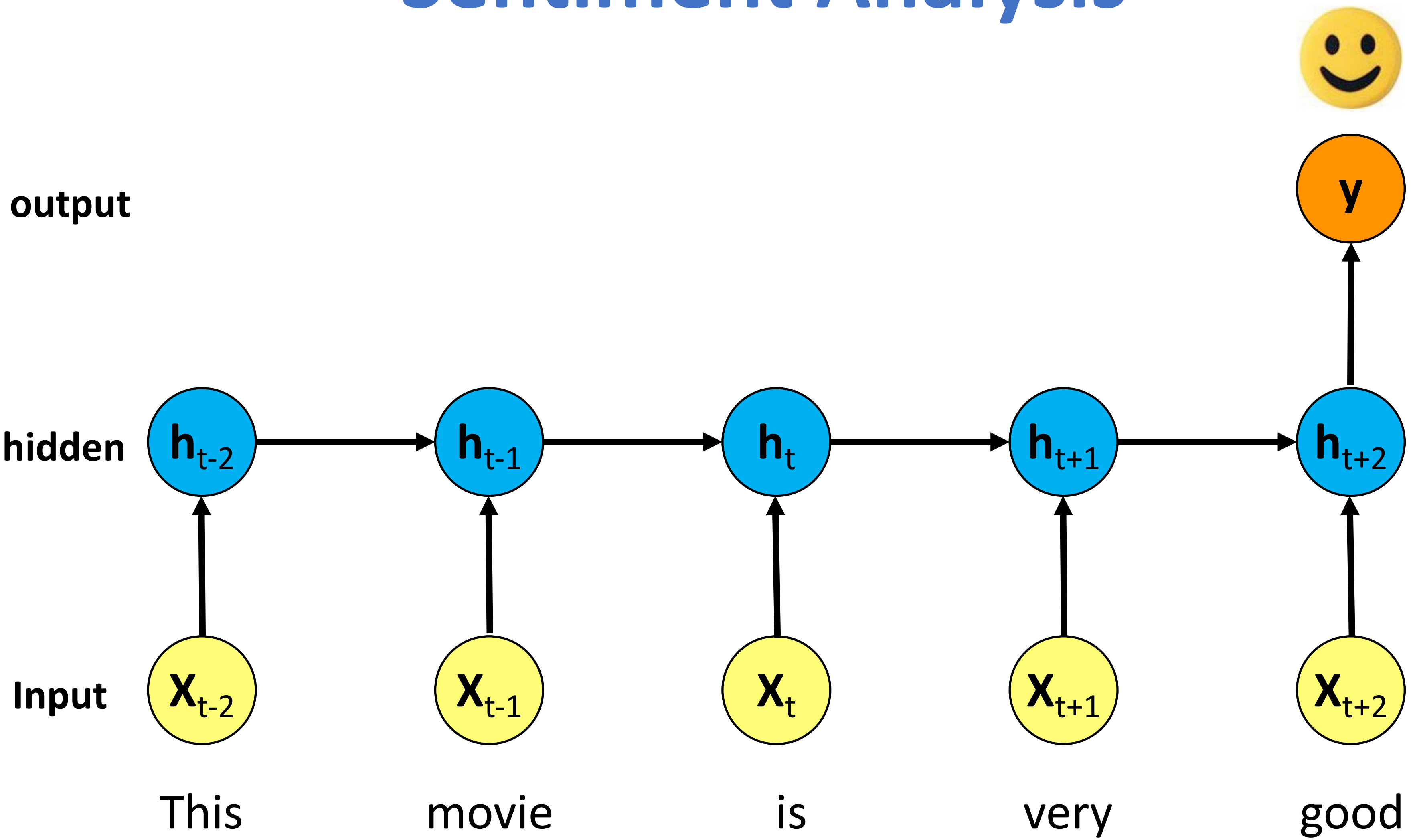
# Recurrent Neural Networks (RNN)
# Time Series Forecasting



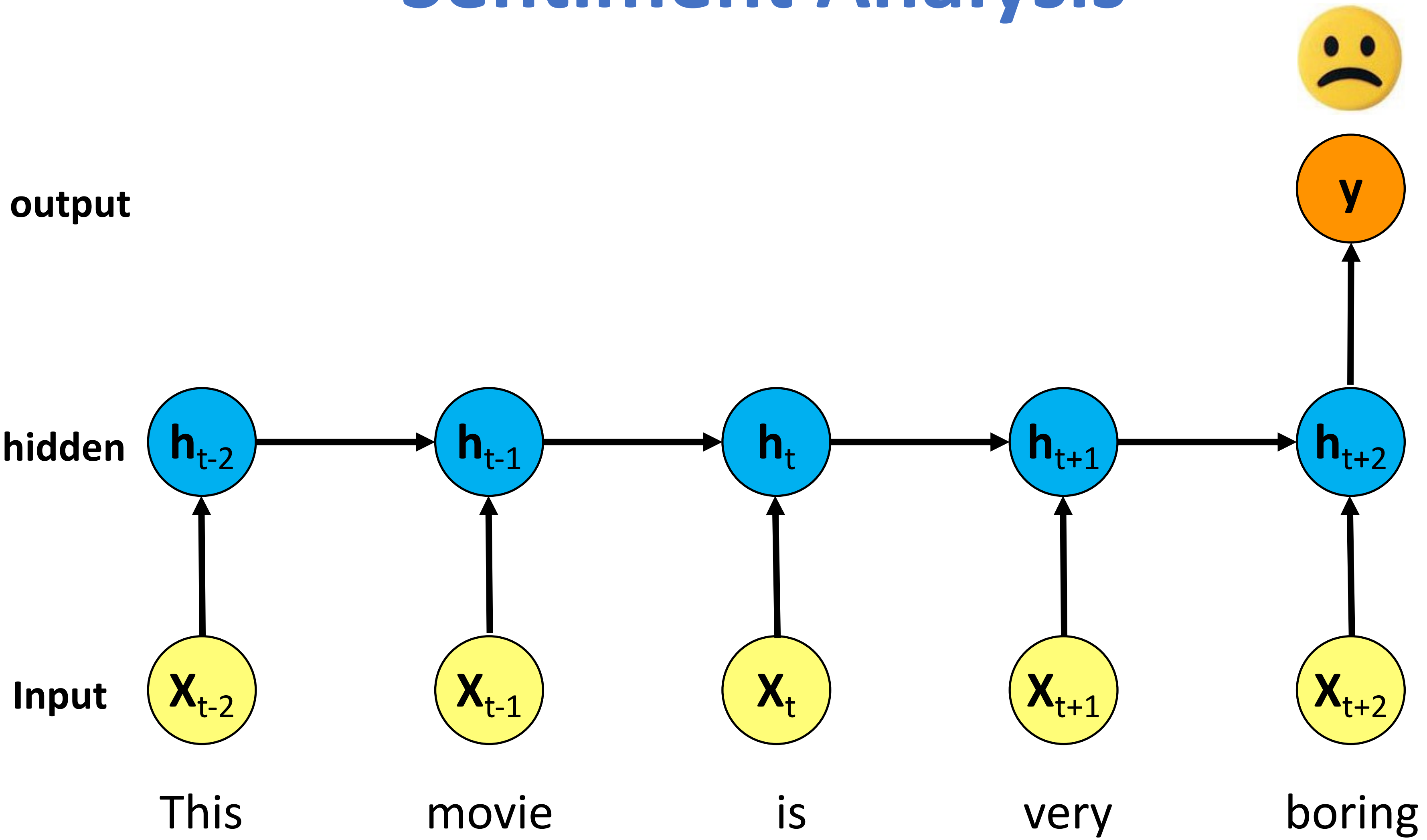
# Recurrent Neural Networks (RNN)



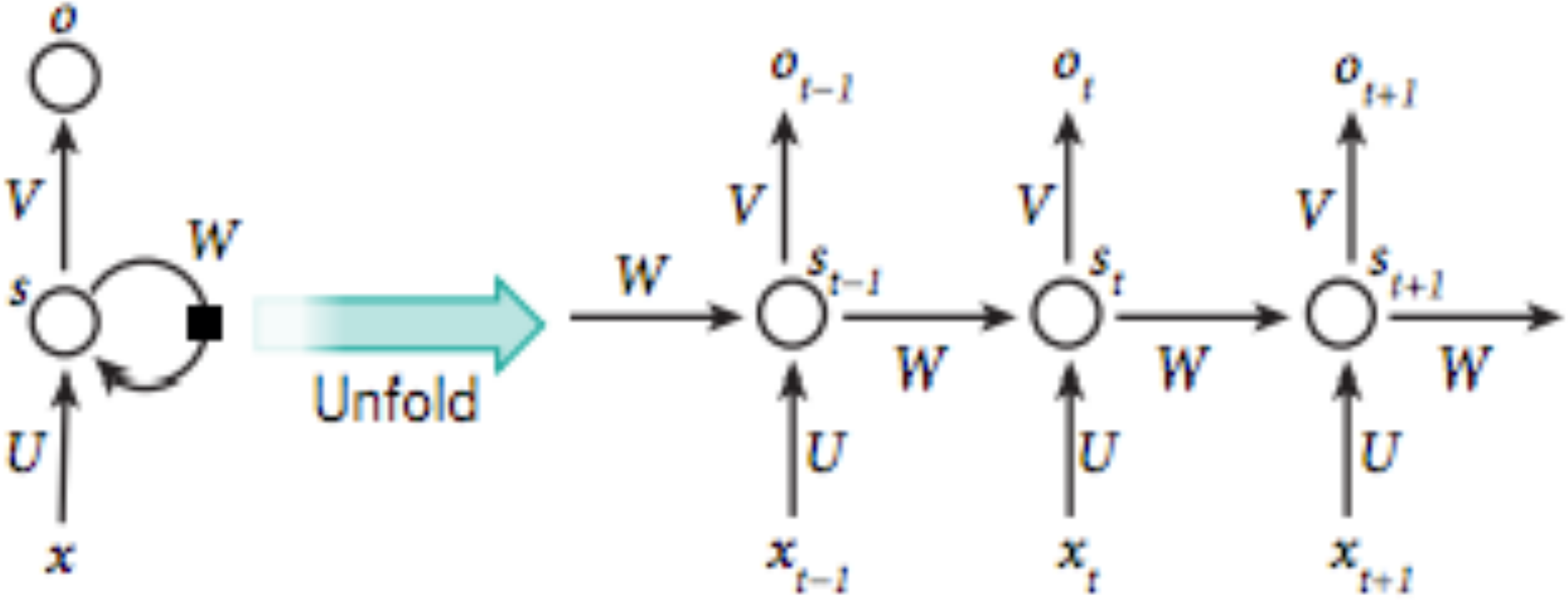
# Recurrent Neural Networks (RNN)
# Sentiment Analysis



# Recurrent Neural Networks (RNN)
# Sentiment Analysis

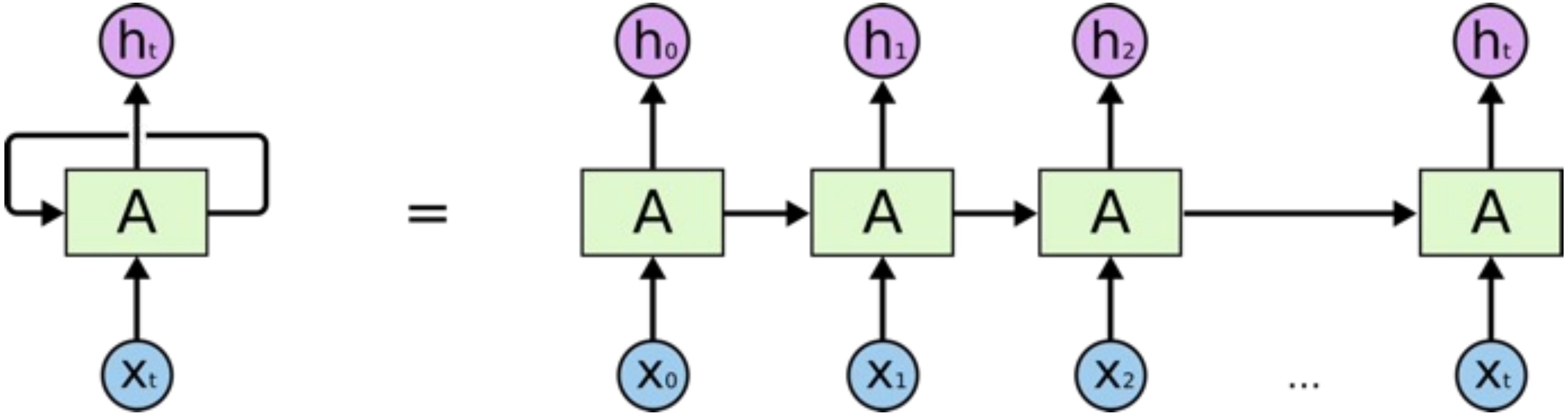


# Recurrent Neural Network (RNN)



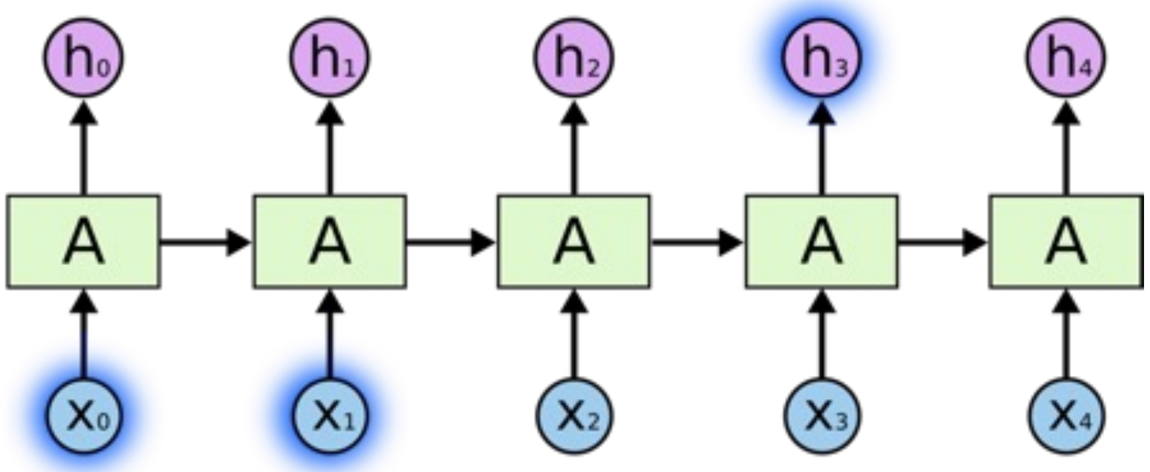

Source: LeCun, Yann, Yoshua Bengio, and Geoffrey Hinton. "Deep learning." Nature 521, no. 7553 (2015): 436-444.

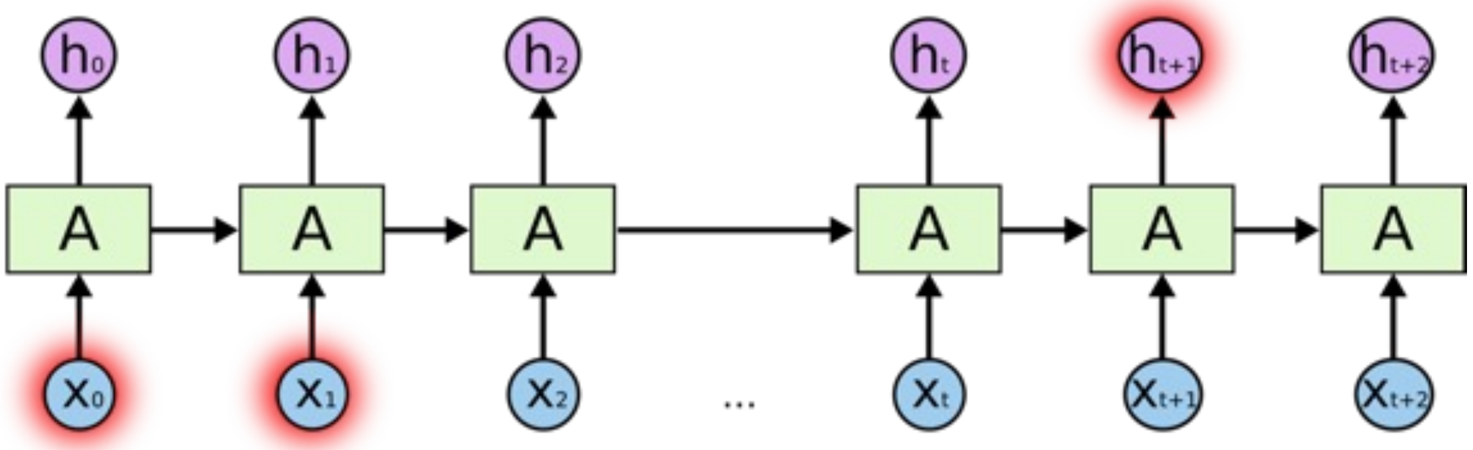
# RNN




Source: Christopher Olah, (2015) Understanding LSTM Networks, http://colah.github.io/posts/2015-08-Understanding-LSTMs/

# RNN long-term dependencies

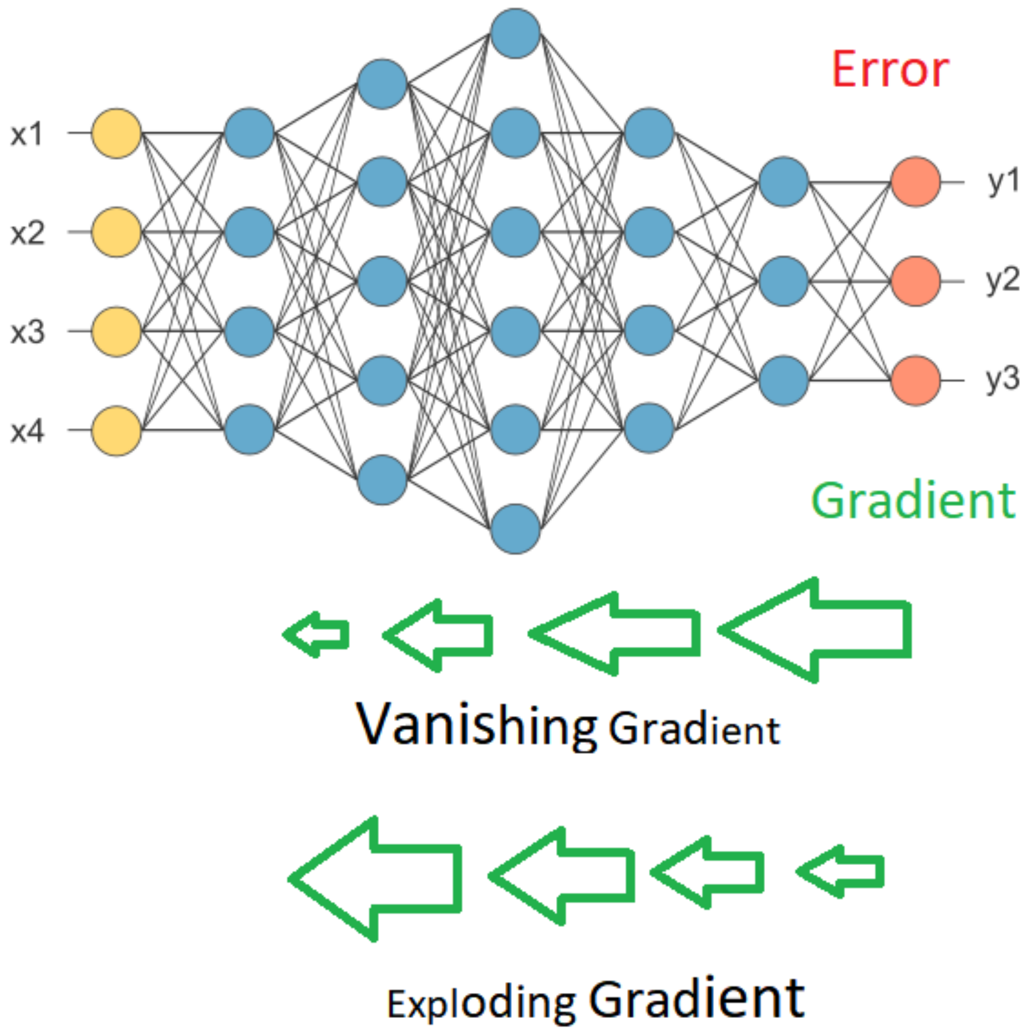


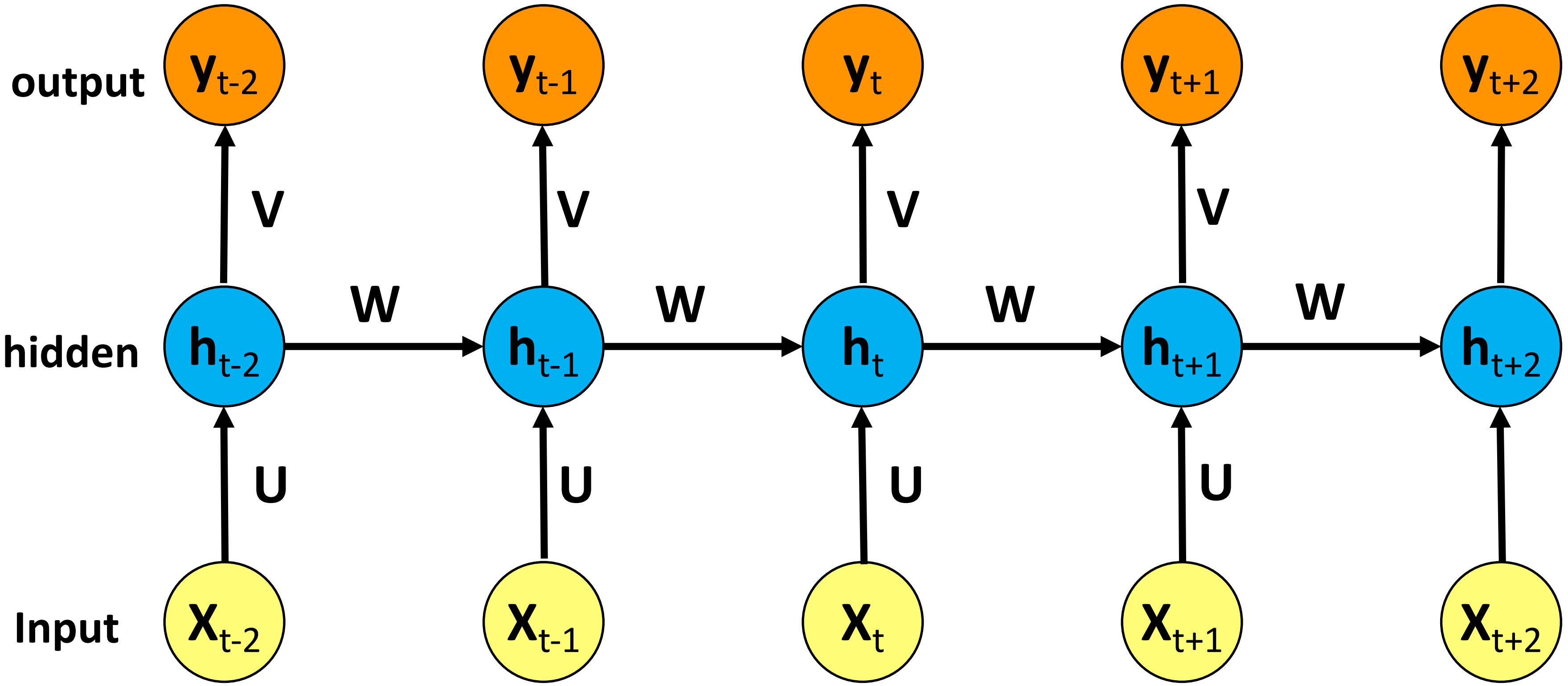

I grew up in France… I speak fluent French.

Source: Christopher Olah, (2015) Understanding LSTM Networks, http://colah.github.io/posts/2015-08-Understanding-LSTMs/

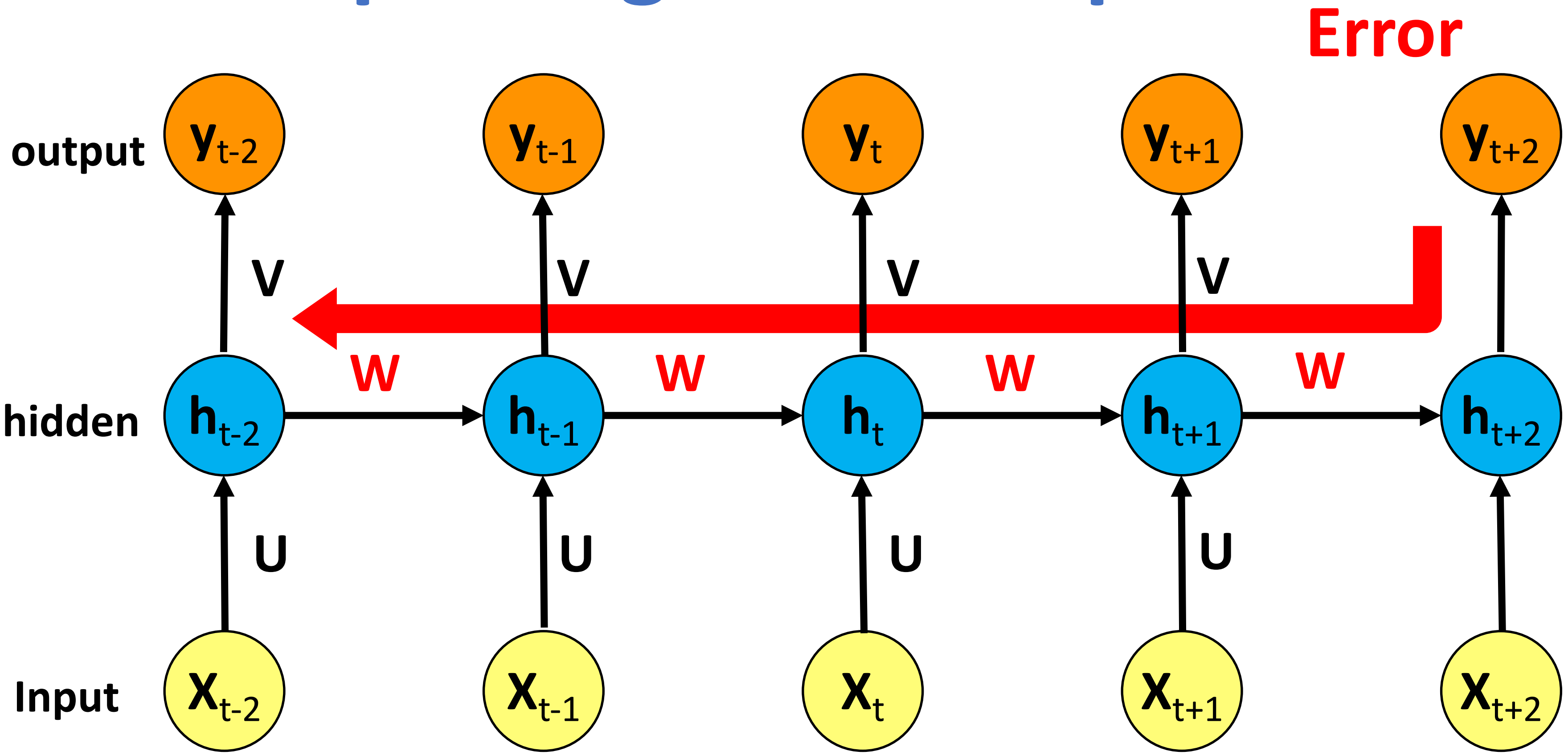
# Vanishing Gradient
# Exploding Gradient



# Recurrent Neural Networks (RNN)



# RNN
# Vanishing Gradient problem
# Exploding Gradient problem

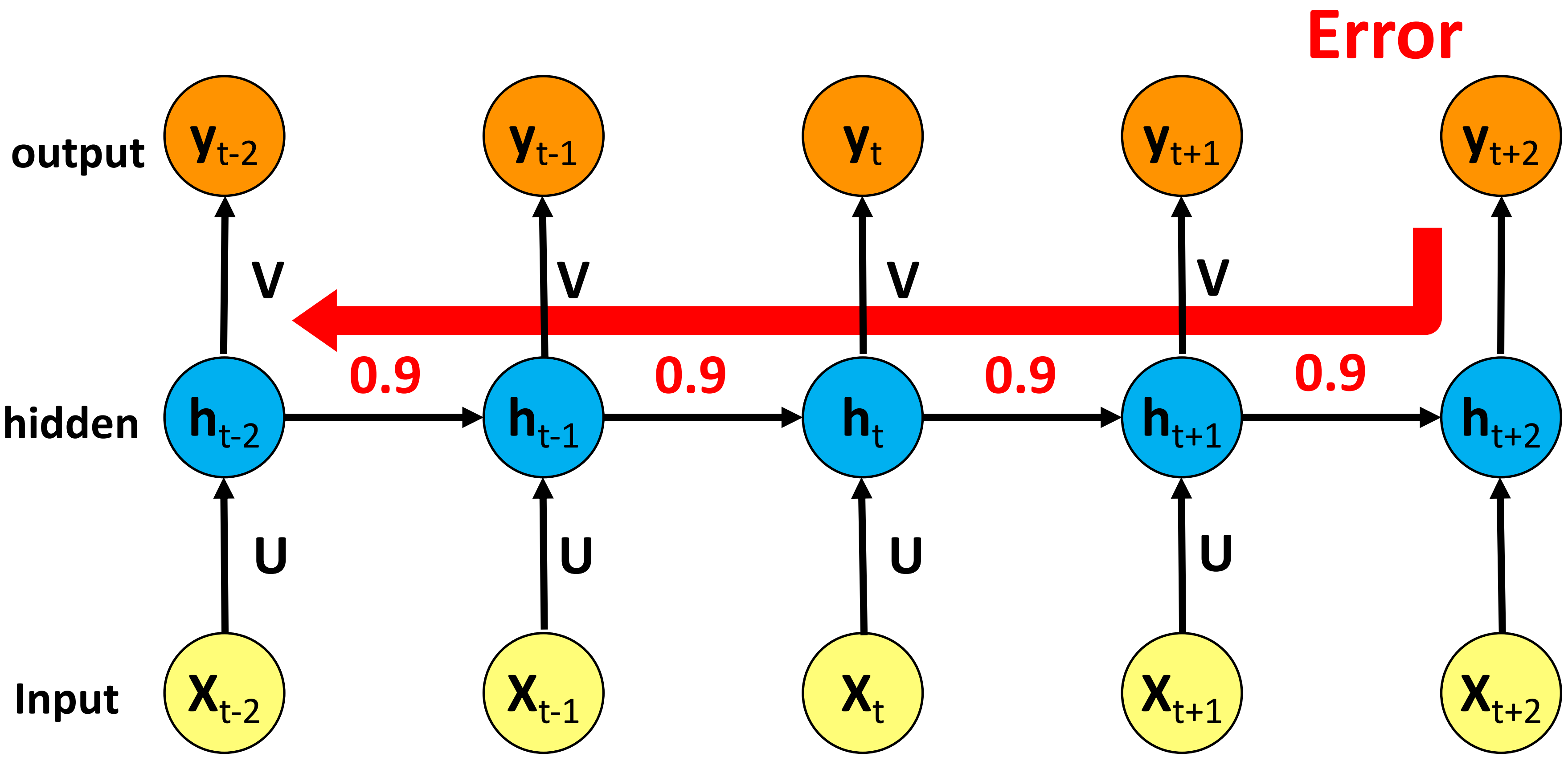



if $|W| < 1$ (Vanishing)

if $|W| > 1$ (Exploding)

Source: https://medium.com/deep-math-machine-learning-ai/chapter-10-1-deepnlp-lstm-long-short-term-memory-networks-with-math-21477f8e4235

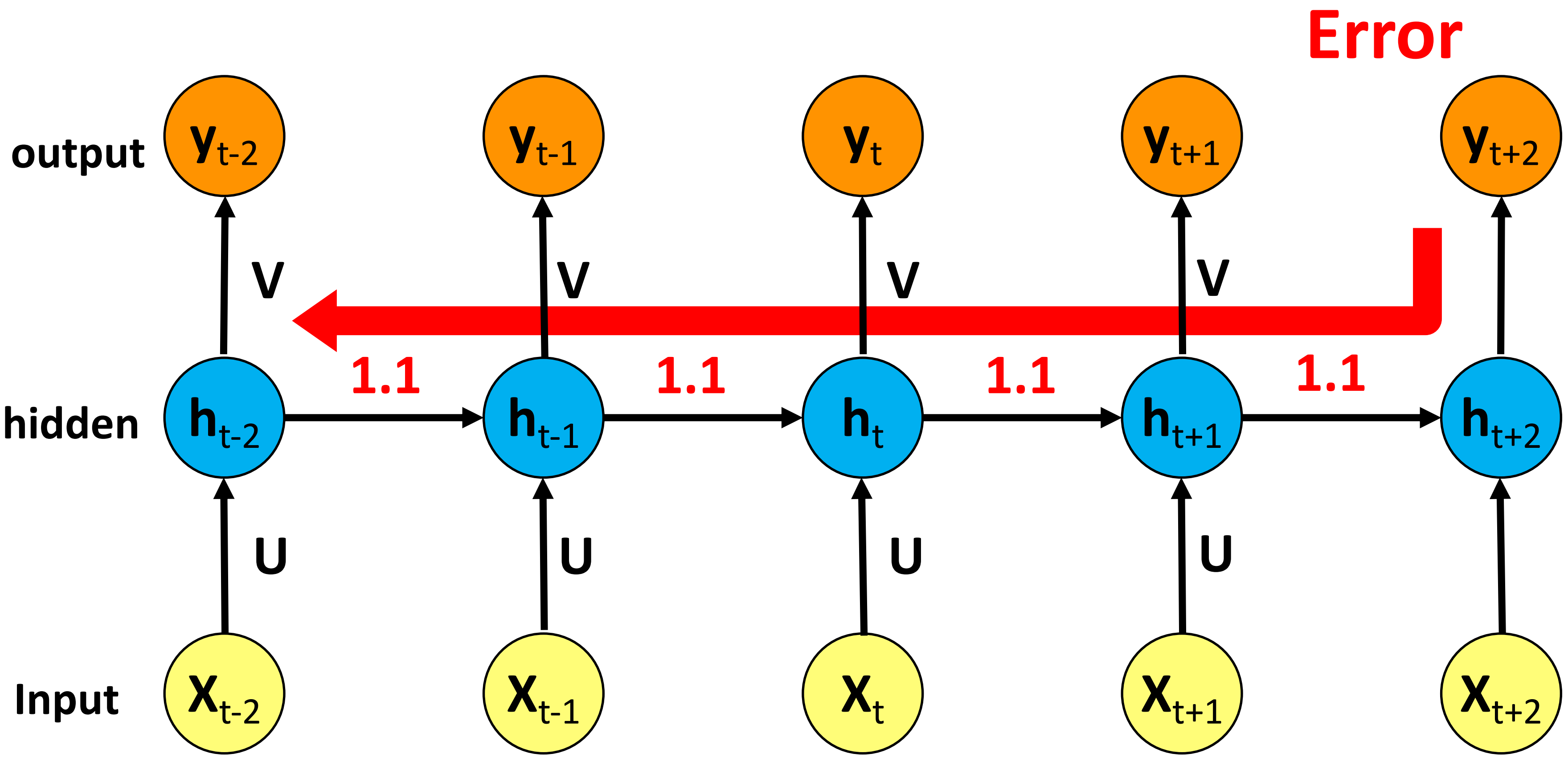
# RNN
# Vanishing Gradient problem




$W = 0.9 < 1$ (Vanishing)

Source: https://medium.com/deep-math-machine-learning-ai/chapter-10-1-deepnlp-lstm-long-short-term-memory-networks-with-math-21477f8e4235

# RNN
# Exploding Gradient problem

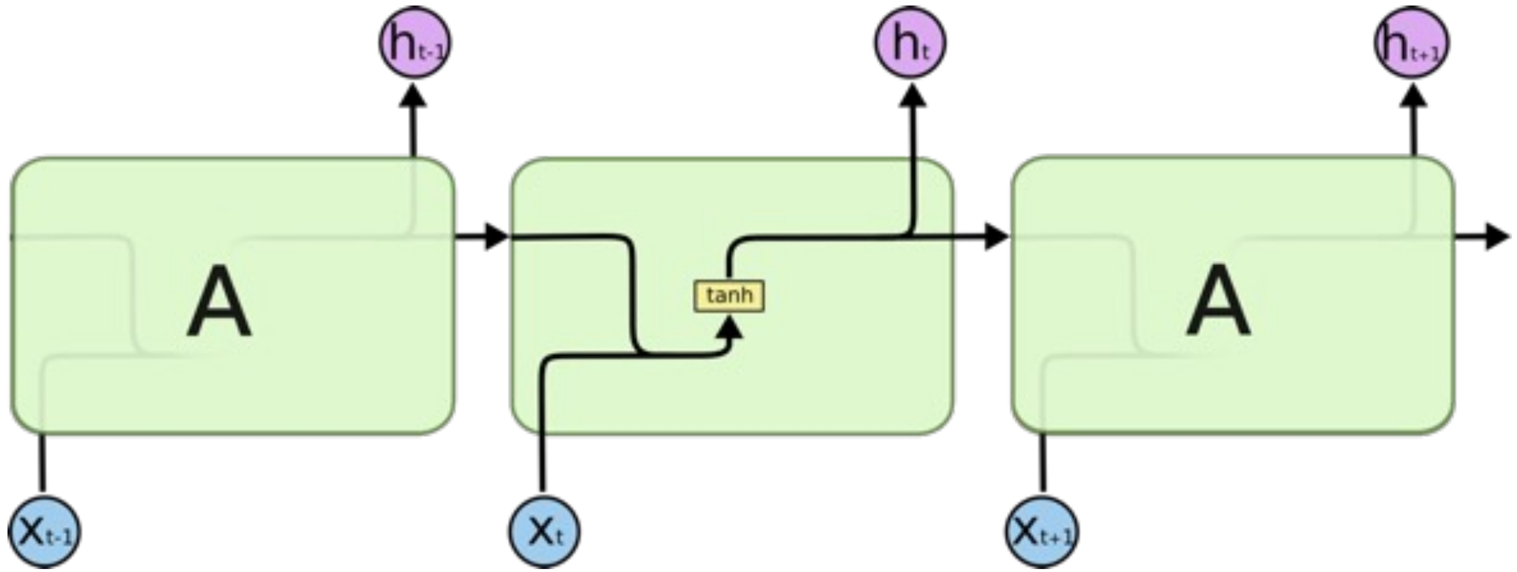



W = 1.1 > 1 (Exploding)

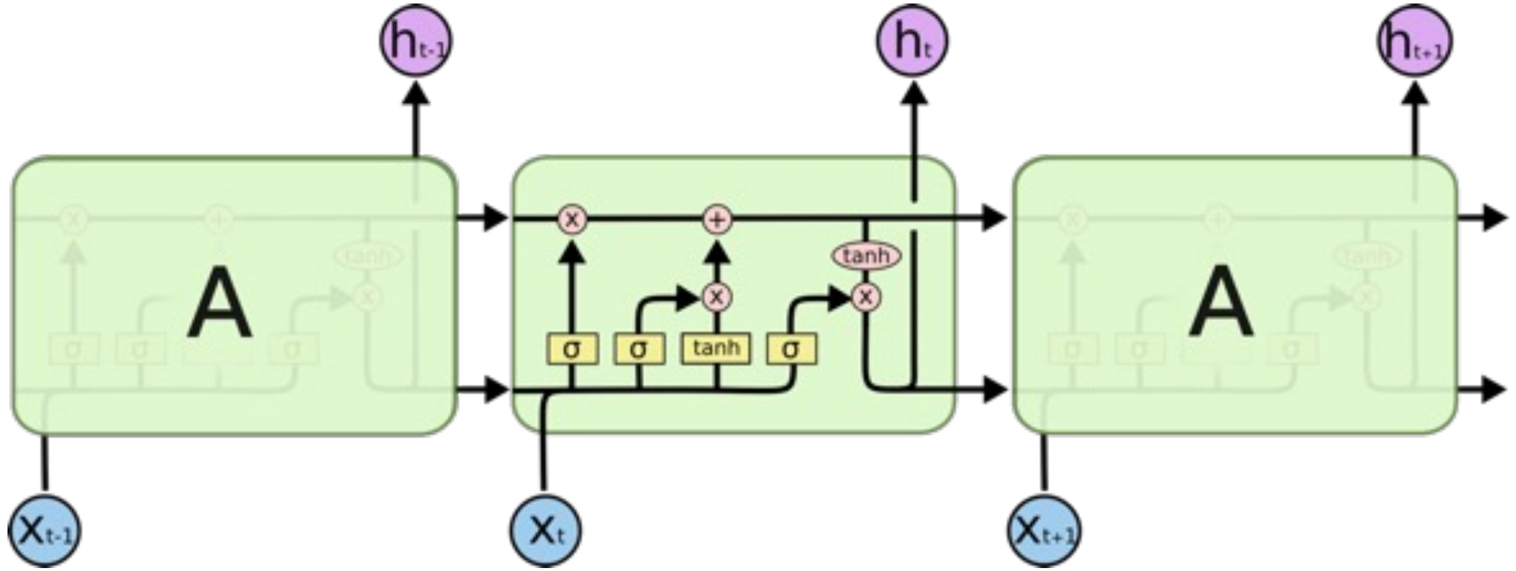
Source: https://medium.com/deep-math-machine-learning-ai/chapter-10-1-deepnlp-lstm-long-short-term-memory-networks-with-math-21477f8e4235

# RNN LSTM

RNN

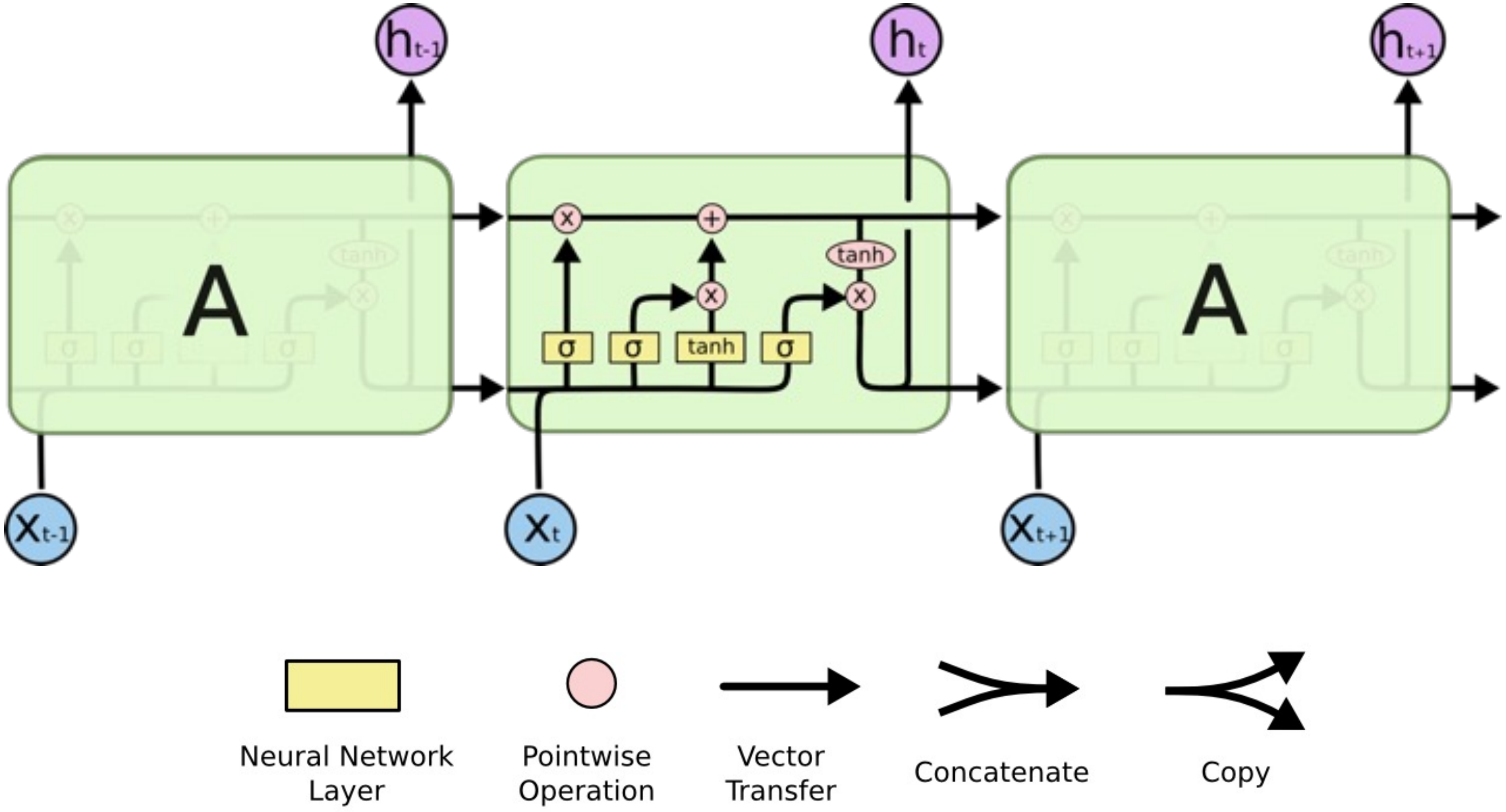



LSTM



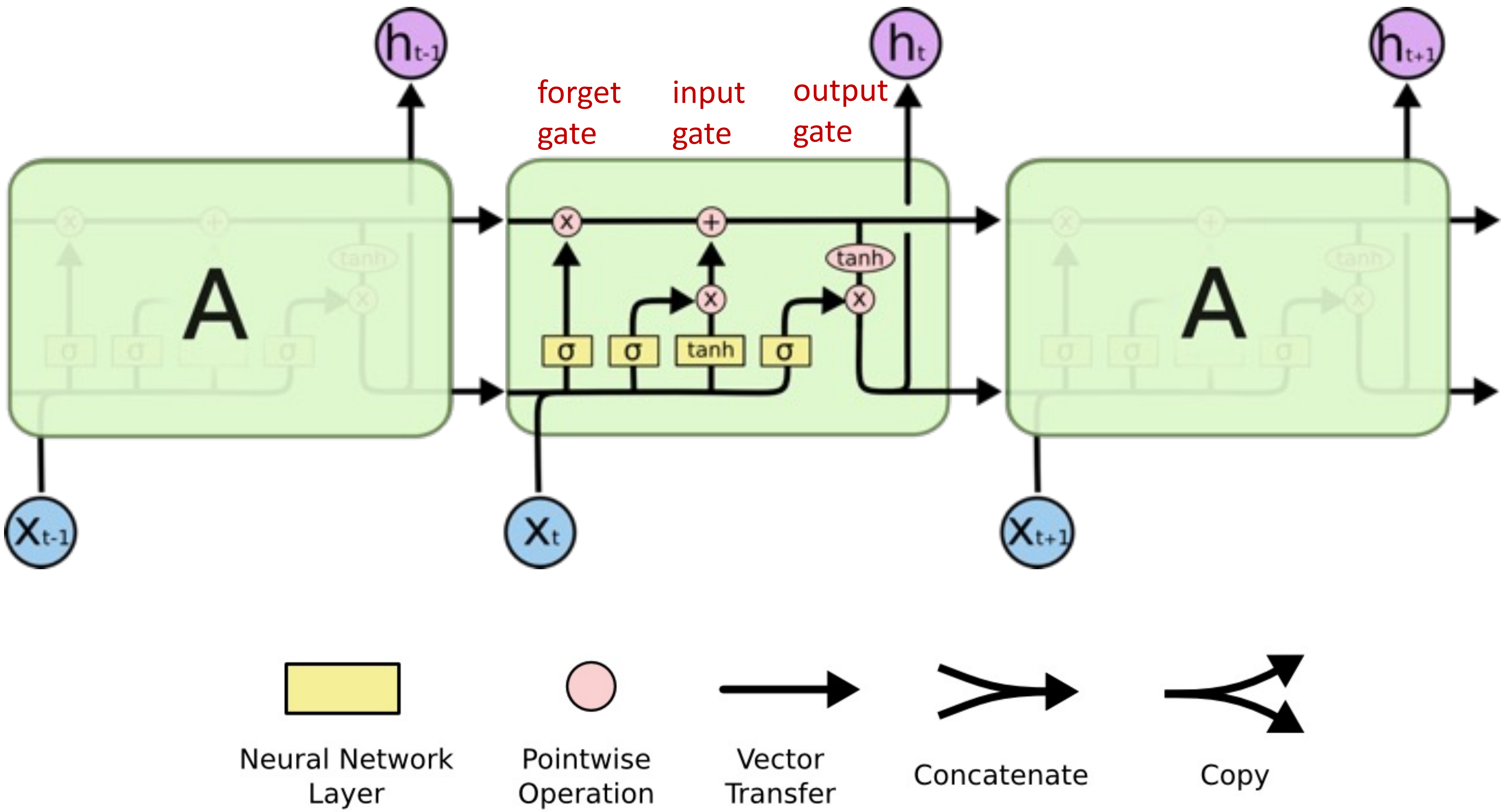

Source: Christopher Olah, (2015) Understanding LSTM Networks, http://colah.github.io/posts/2015-08-Understanding-LSTMs/

# Long Short Term Memory (LSTM)



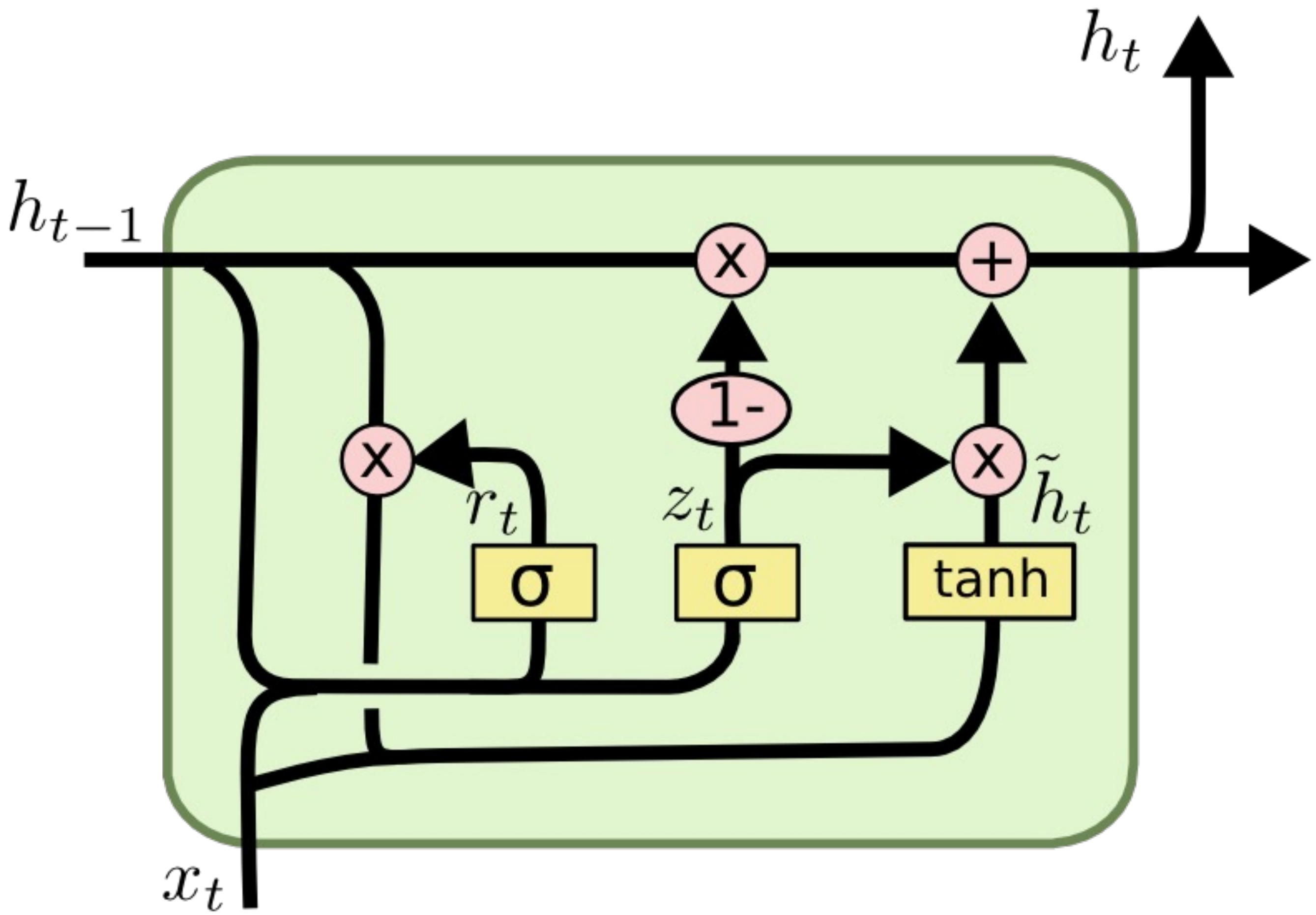

Source: Christopher Olah, (2015) Understanding LSTM Networks, http://colah.github.io/posts/2015-08-Understanding-LSTMs/

# Long Short Term Memory (LSTM)



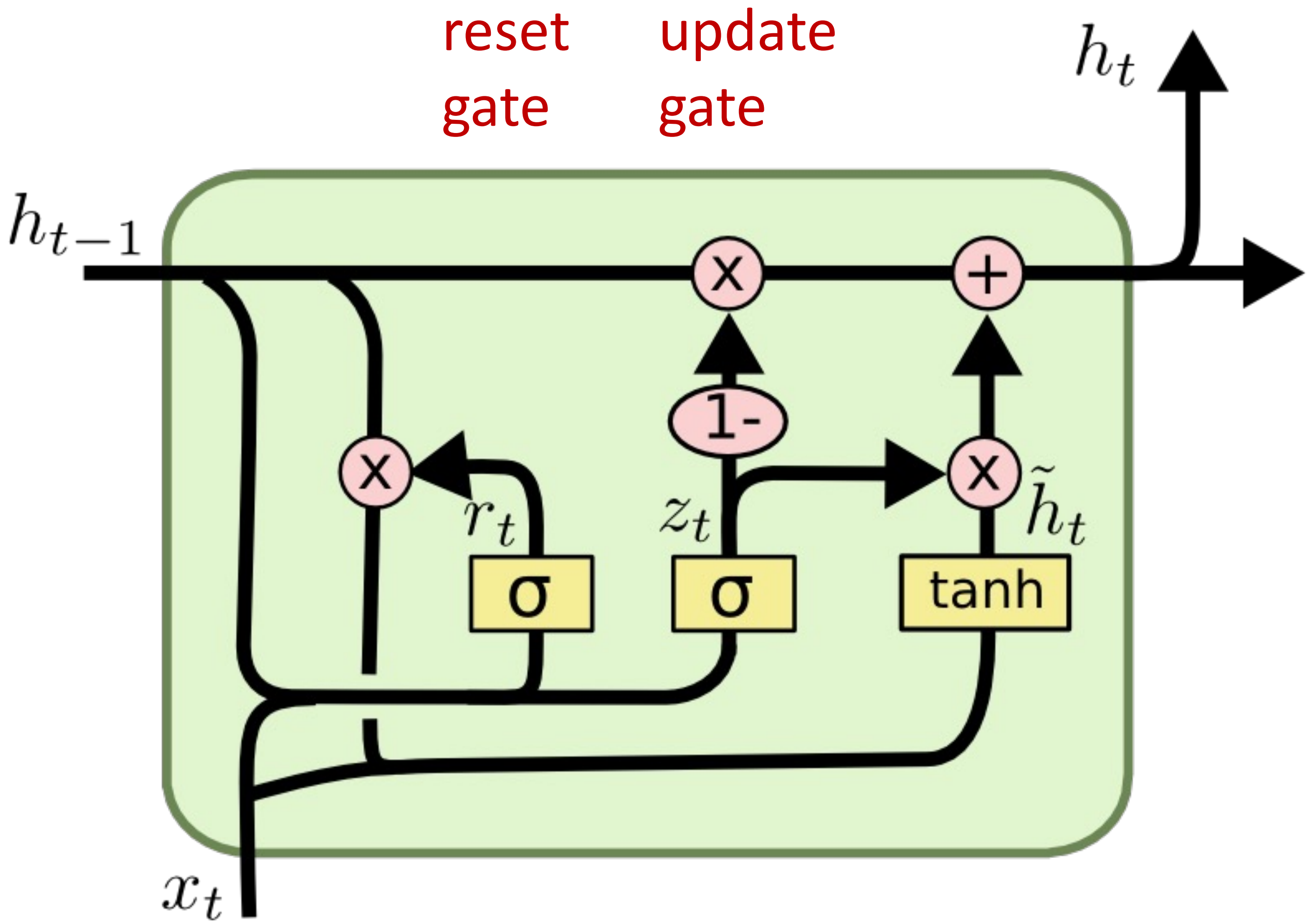

Source: Christopher Olah, (2015) Understanding LSTM Networks, http://colah.github.io/posts/2015-08-Understanding-LSTMs/

# Gated Recurrent Unit (GRU)



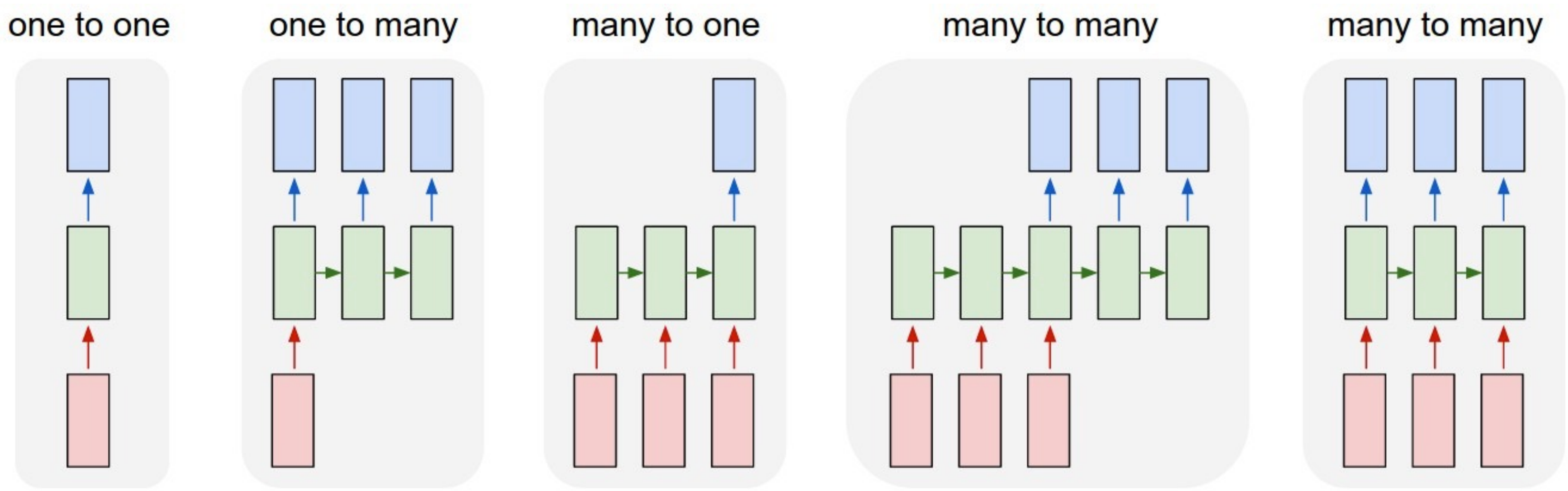

Source: Christopher Olah, (2015) Understanding LSTM Networks, http://colah.github.io/posts/2015-08-Understanding-LSTMs/

# Gated Recurrent Unit (GRU)




Source: Christopher Olah, (2015) Understanding LSTM Networks, http://colah.github.io/posts/2015-08-Understanding-LSTMs/

# LSTM Recurrent Neural Network




Traditional Neural Network

Music Generation

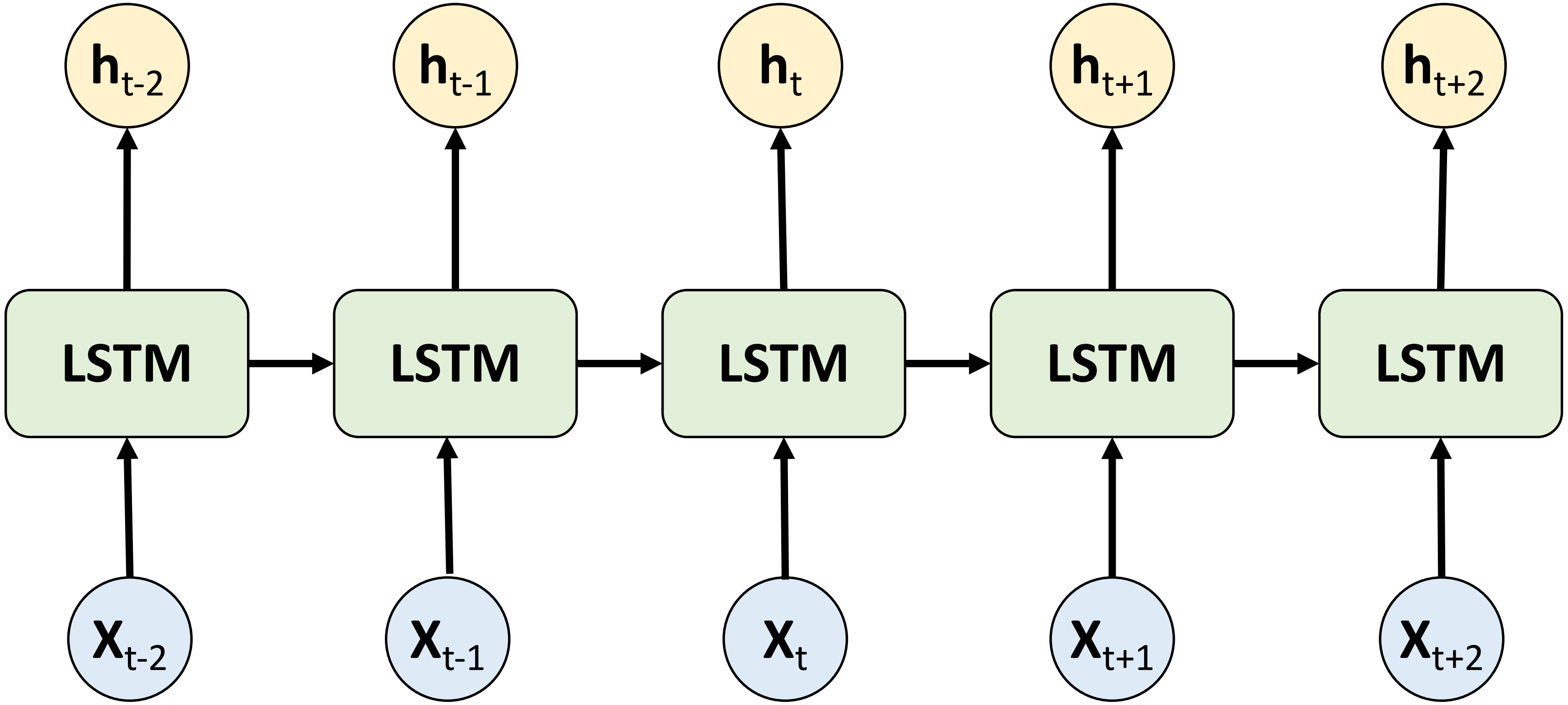
Sentiment Classification

Name Entity Recognition

Machine Translation

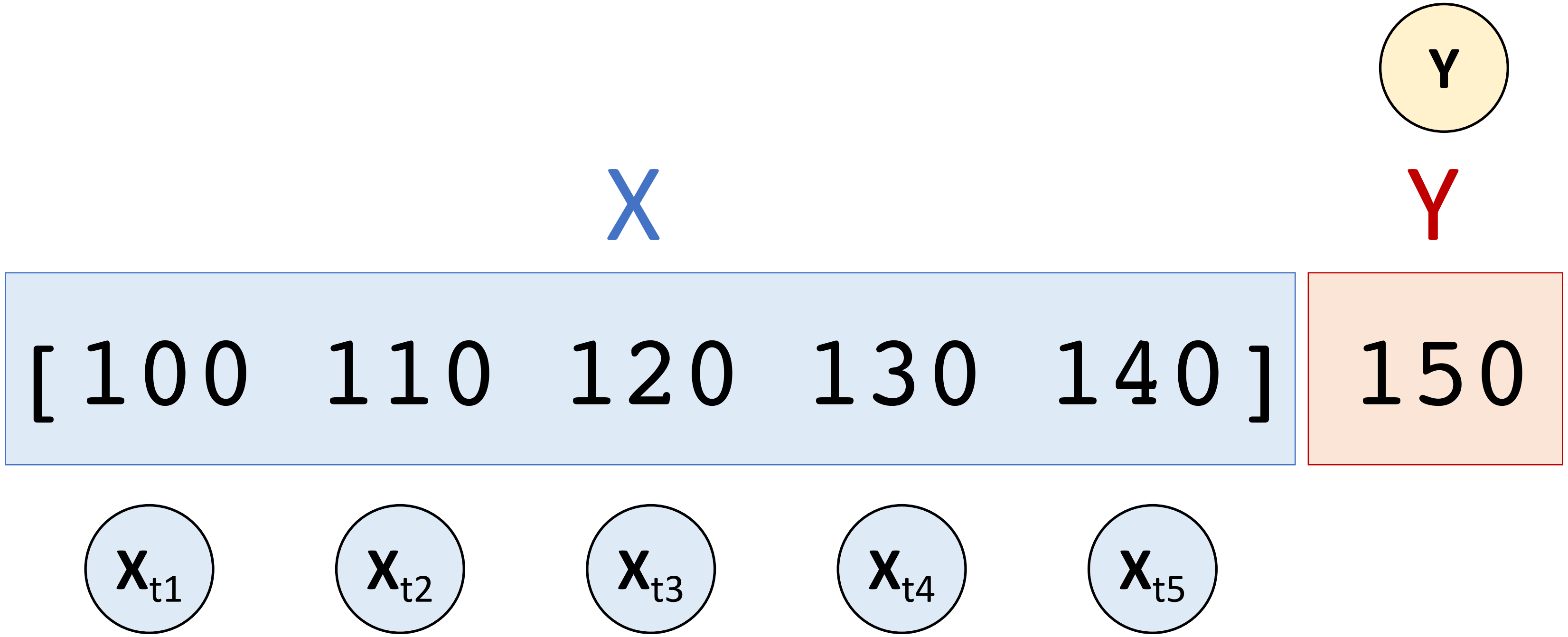
Source: https://github.com/Vict0rSch/deep_learning/tree/master/keras/recurrent

# Long Short Term Memory (LSTM) for Time Series Forecasting



# Time Series Data

[100, 110, 120, 130, 140, 150]

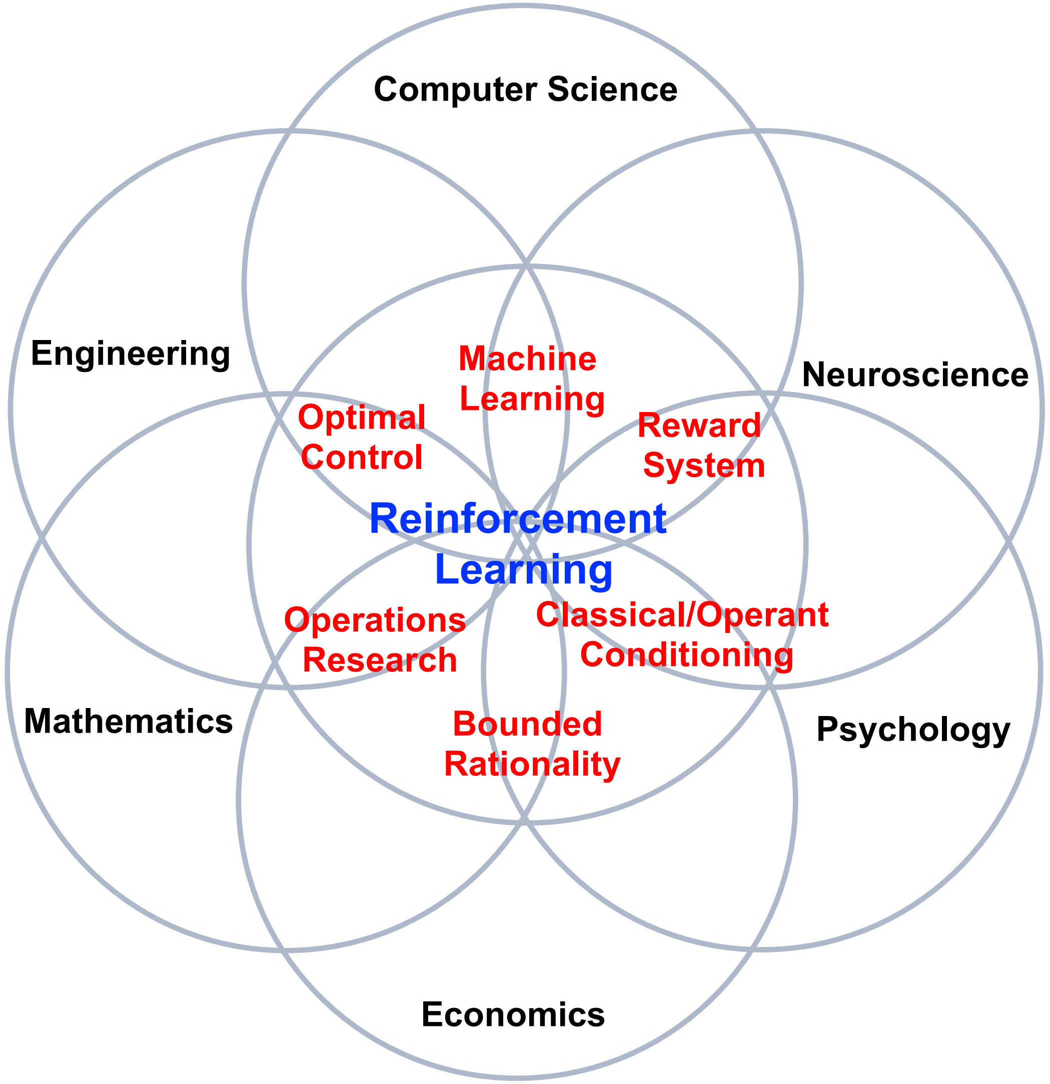


# Time Series Data

[10, 20, 30, 40, 50, 60, 70, 80, 90]

| X | Y |
|---|---|
| [10 20 30] | 40 |
| [20 30 40] | 50 |
| [30 40 50] | 60 |
| [40 50 60] | 70 |
| [50 60 70] | 80 |
| [60 70 80] | 90 |

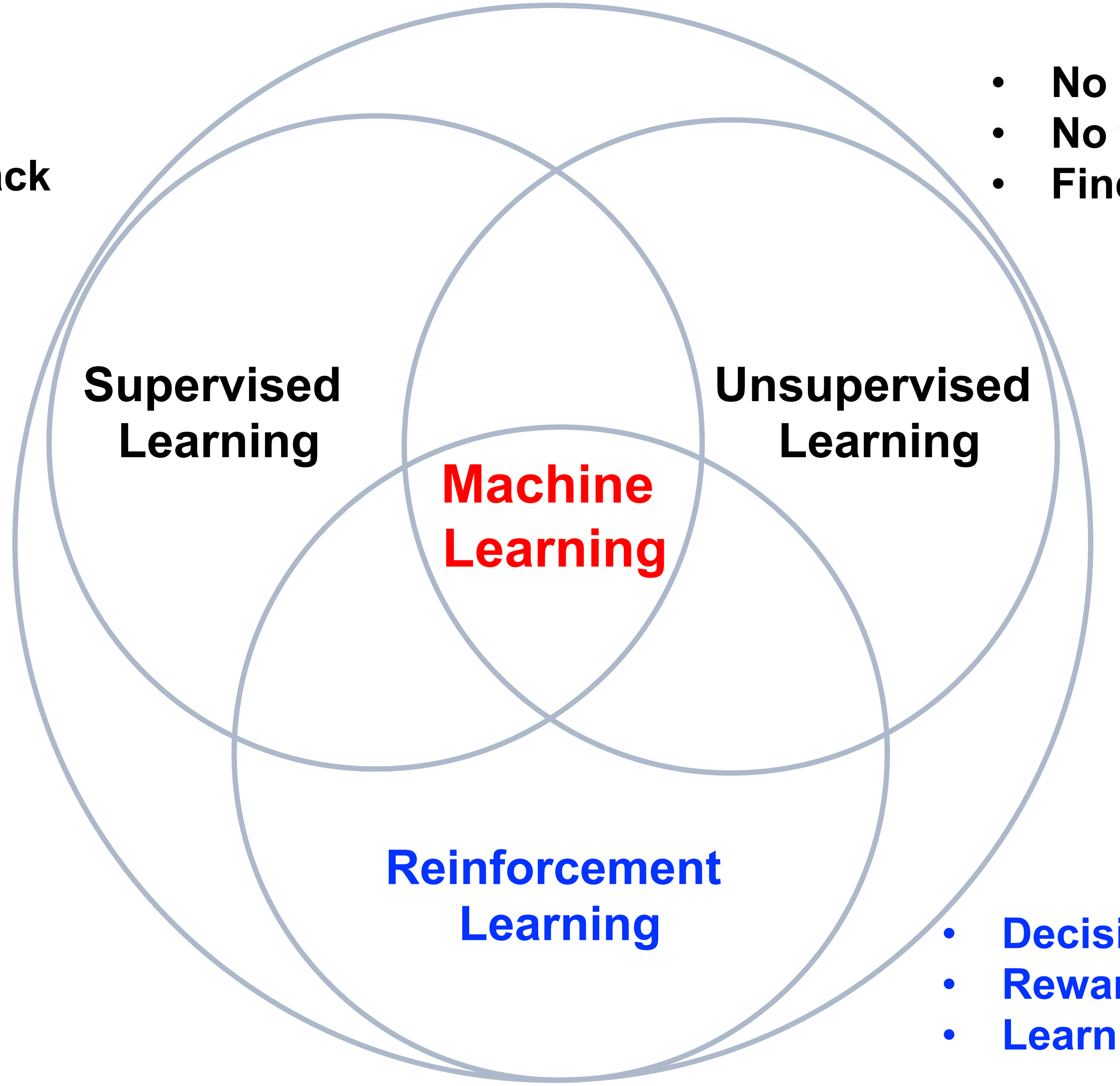
# Reinforcement Learning (RL)




Source: David Silver (2015), Introduction to reinforcement learning, https://www.youtube.com/playlist?list=PLqYmG7hTraZDM-OYHWgPebj2MfCFzFObQ

# Branches of Machine Learning (ML) Reinforcement Learning (RL)

- Labeled data
- Direct feedback
- Predict

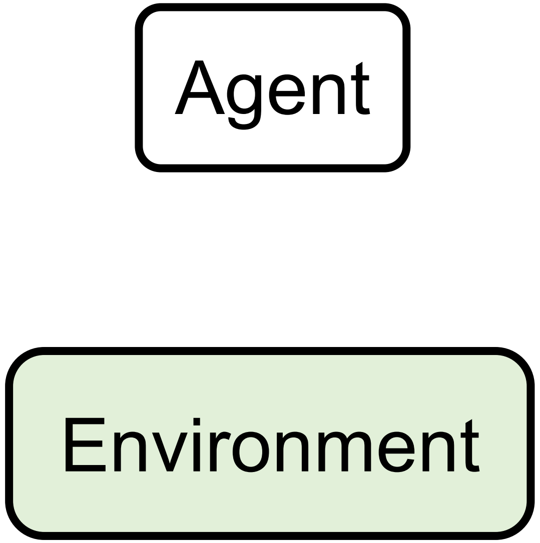



- No Labels
- No feedback
- Find hidden structure

- Decision process
- Reward system
- Learn series of actions

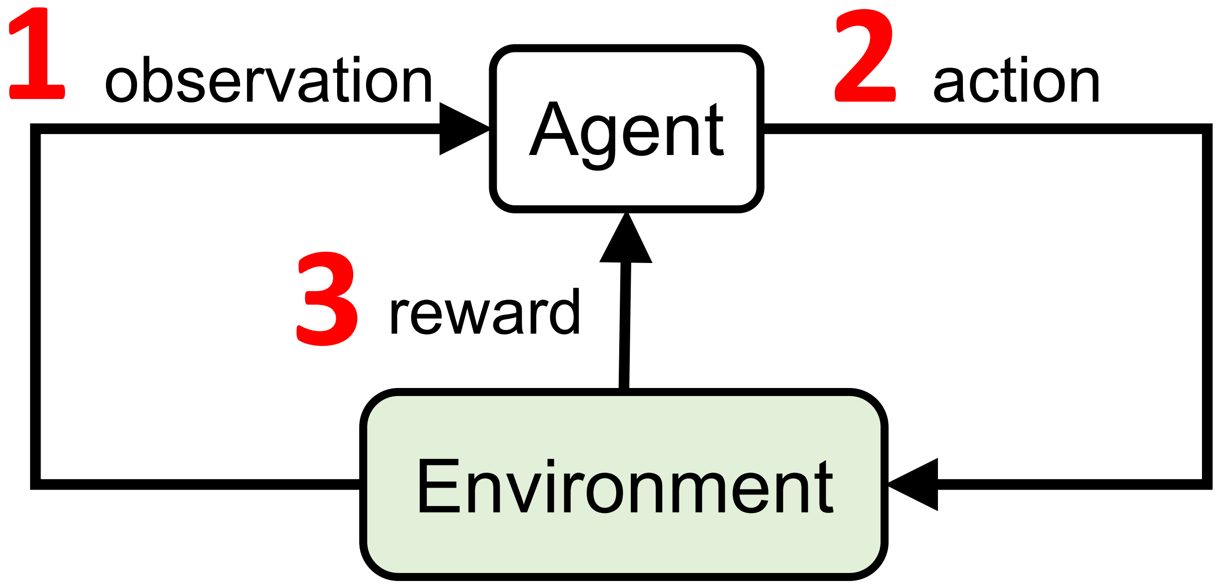
Source: David Silver (2015), Introduction to reinforcement learning, https://www.youtube.com/playlist?list=PLqYmG7hTraZDM-OYHWgPebj2MfCFzFObQ

# Reinforcement Learning (DL)



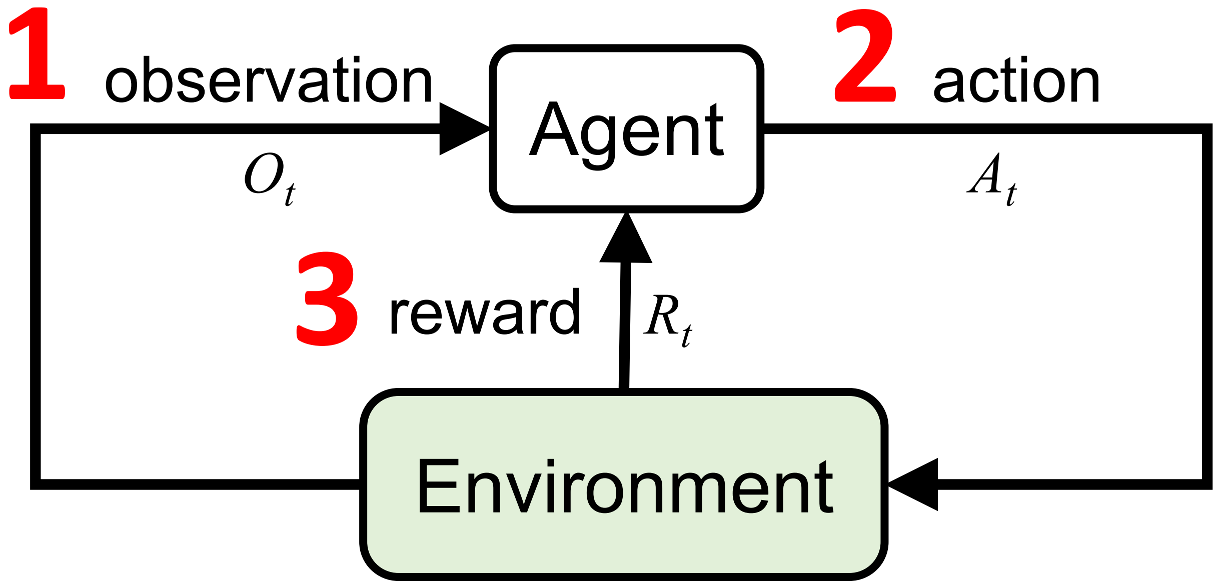

Source: Richard S. Sutton & Andrew G. Barto (2018), Reinforcement Learning: An Introduction, 2nd Edition, A Bradford Book.

# Reinforcement Learning (DL)




Source: Richard S. Sutton & Andrew G. Barto (2018), Reinforcement Learning: An Introduction, 2nd Edition, A Bradford Book.

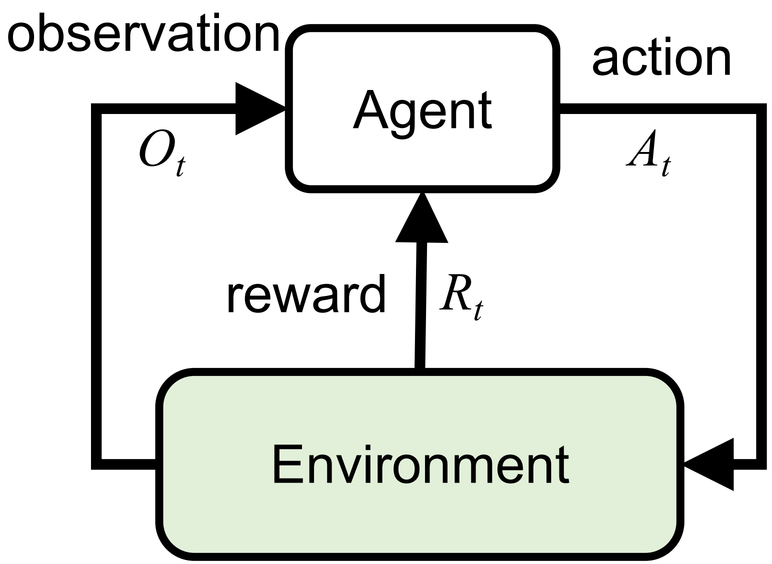
# Reinforcement Learning (DL)




Source: Richard S. Sutton & Andrew G. Barto (2018), Reinforcement Learning: An Introduction, 2nd Edition, A Bradford Book.

# Agent and Environment

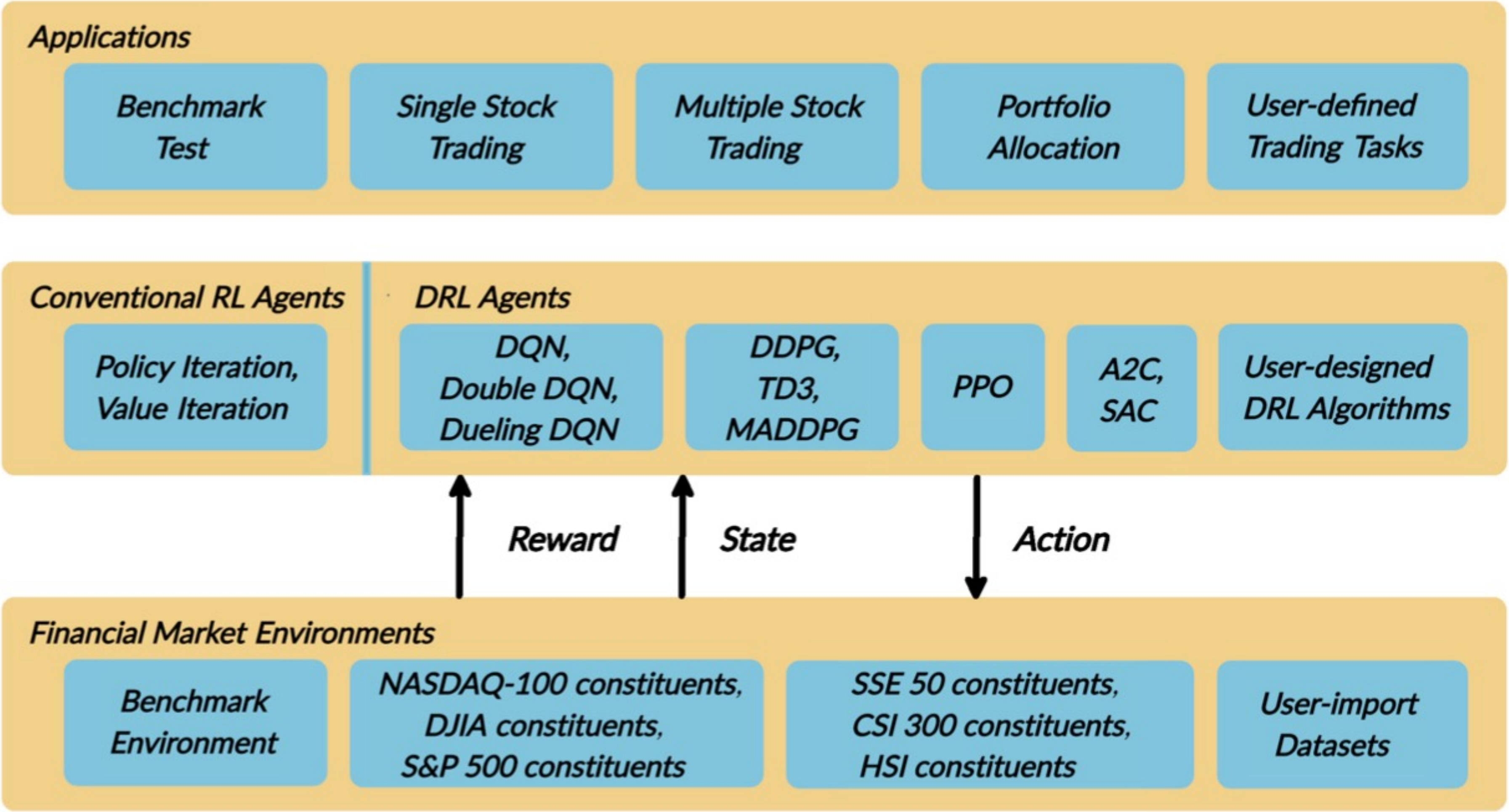
- **At each step *t* the agent:**
  - **Executes action $A_t$**
  - **Receives observation $O_t$**
  - **Receives scalar reward $R_t$**
- **The environment:**
  - **Receives action $A_t$**
  - **Emits observation $O_{t+1}$**
  - **Emits scalar reward $R_{t+1}$**
- **t increments at env. step**




Source: David Silver (2015), Introduction to reinforcement learning, https://www.youtube.com/playlist?list=PLqYmG7hTraZDM-OYHWgPebj2MfCFzFObQ

# FinRL:

## A Deep Reinforcement Learning Library for Automated Stock Trading in Quantitative Finance




Source: Xiao-Yang Liu, Hongyang Yang, Qian Chen, Runjia Zhang, Liuqing Yang, Bowen Xiao, and Christina Dan Wang (2020). "FinRL: A Deep Reinforcement Learning Library for Automated Stock Trading in Quantitative Finance." arXiv preprint arXiv:2011.09607 (2020).

# FinRL

## Deep Reinforcement Learning Algorithms

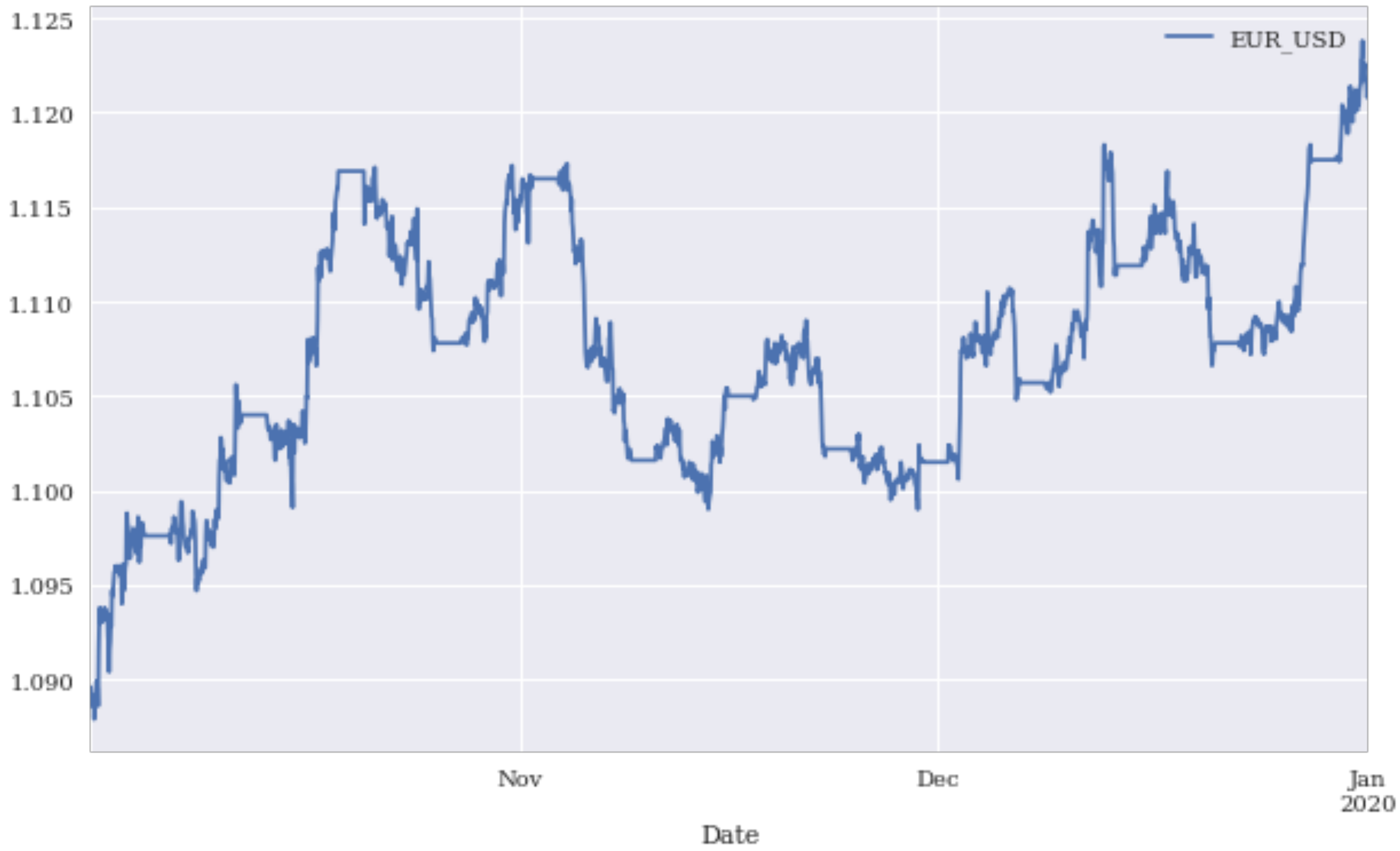
| Algorithms | Input | Output | Type | State-action spaces support | Finance use cases support | Features and Improvements | Advantages |
|---|---|---|---|---|---|---|---|
| DQN | States | Q-value | Value based | Discrete only | Single stock trading | Target network, experience replay | Simple and easy to use |
| Double DQN | States | Q-value | Value based | Discrete only | Single stock trading | Use two identical neural network models to learn | Reduce overestimations |
| Dueling DQN | States | Q-value | Value based | Discrete only | Single stock trading | Add a specialized dueling Q head | Better differentiate actions, improves the learning |
| DDPG | State action pair | Q-value | Actor-critic based | Continuous only | Multiple stock trading, portfolio allocation | Being deep Q-learning for continuous action spaces | Better at handling high-dimensional continuous action spaces |
| A2C | State action pair | Q-value | Actor-critic based | Discrete and continuous | All use cases | Advantage function, parallel gradients updating | Stable, cost-effective, faster and works better with large batch sizes |
| PPO | State action pair | Q-value | Actor-critic based | Discrete and continuous | All use cases | Clipped surrogate objective function | Improve stability, less variance, simply to implement |
| SAC | State action pair | Q-value | Actor-critic based | Continuous only | Multiple stock trading, portfolio allocation | Entropy regularization, exploration-exploitation trade-off | Improve stability |
| TD3 | State action pair | Q-value | Actor-critic based | Continuous only | Multiple stock trading, portfolio allocation | Clipped double Q-Learning, delayed policy update, target policy smoothing. | Improve DDPG performance |
| MADDPG | State action pair | Q-value | Actor-critic based | Continuous only | Multiple stock trading, portfolio allocation | Handle multi-agent RL problem | Improve stability and performance |

Source: Xiao-Yang Liu, Hongyang Yang, Qian Chen, Runjia Zhang, Liuqing Yang, Bowen Xiao, and Christina Dan Wang (2020). "FinRL: A Deep Reinforcement Learning Library for Automated Stock Trading in Quantitative Finance." arXiv preprint arXiv:2011.09607 (2020).

```python
import os
import numpy as np
import pandas as pd
from pylab import plt, mpl
plt.style.use('seaborn')
mpl.rcParams['savefig.dpi'] = 300
mpl.rcParams['font.family'] = 'serif'
pd.set_option('precision', 4)
np.set_printoptions(suppress=True, precision=4)
os.environ['PYTHONHASHSEED'] = '0'
```

```python
url = 'http://hilpisch.com/aiif_eikon_id_eur_usd.csv'
symbol = 'EUR_USD'
raw = pd.read_csv(url, index_col=0, parse_dates=True)
raw.head()
```

# Mid-closing prices for EUR/USD (intraday)




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

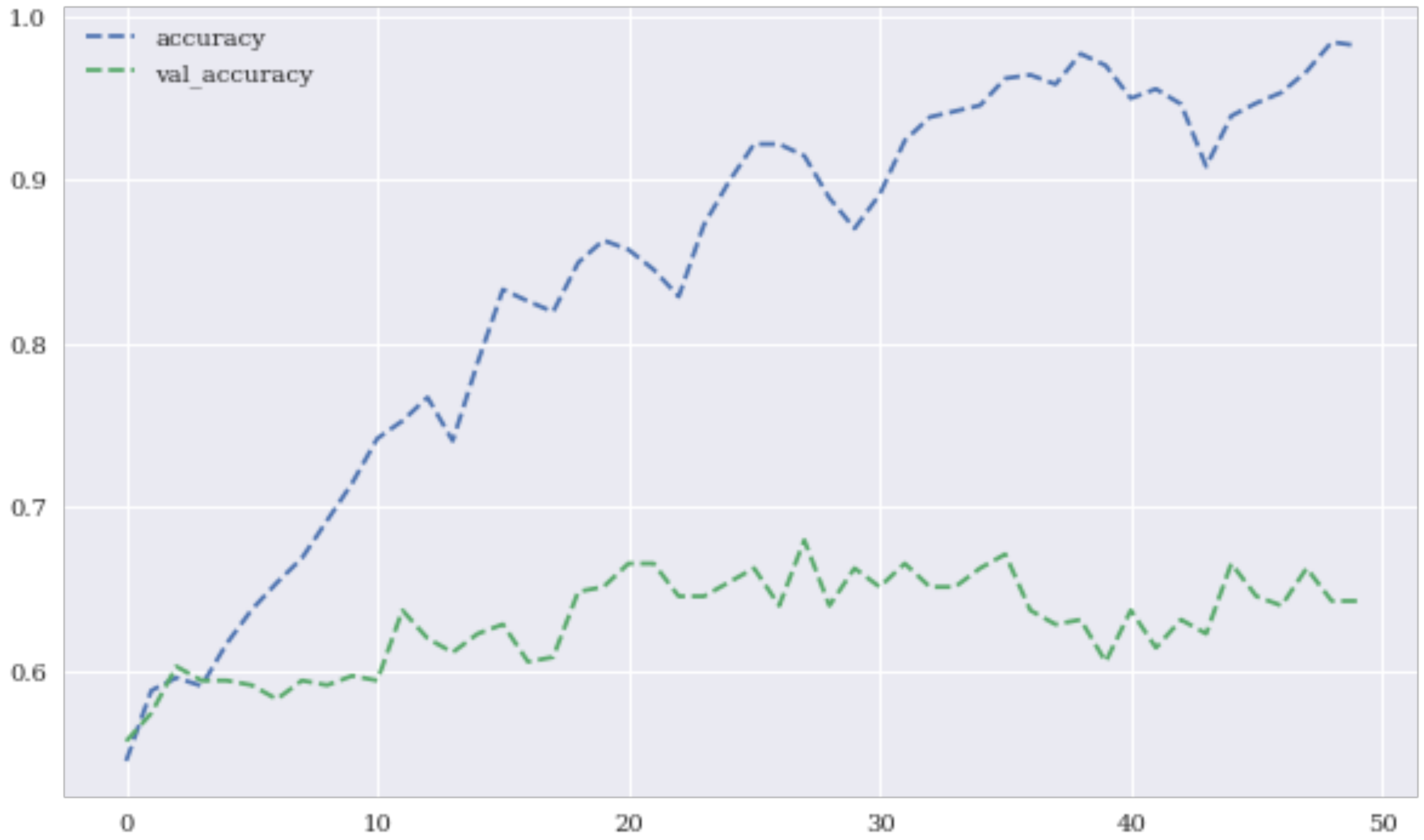
```python
optimizer = Adam(lr=0.001)

def create_model(hl=1, hu=128, optimizer=optimizer):
    model = Sequential()
    model.add(Dense(hu, input_dim=len(cols),
                    activation='relu'))
    for _ in range(hl):
        model.add(Dense(hu, activation='relu'))
    model.add(Dense(1, activation='sigmoid'))
    model.compile(loss='binary_crossentropy',
                      optimizer=optimizer,
                      metrics=['accuracy'])
    return model

set_seeds()
model = create_model(hl=1, hu=128)
model.summary()
```

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Training and validation accuracy values

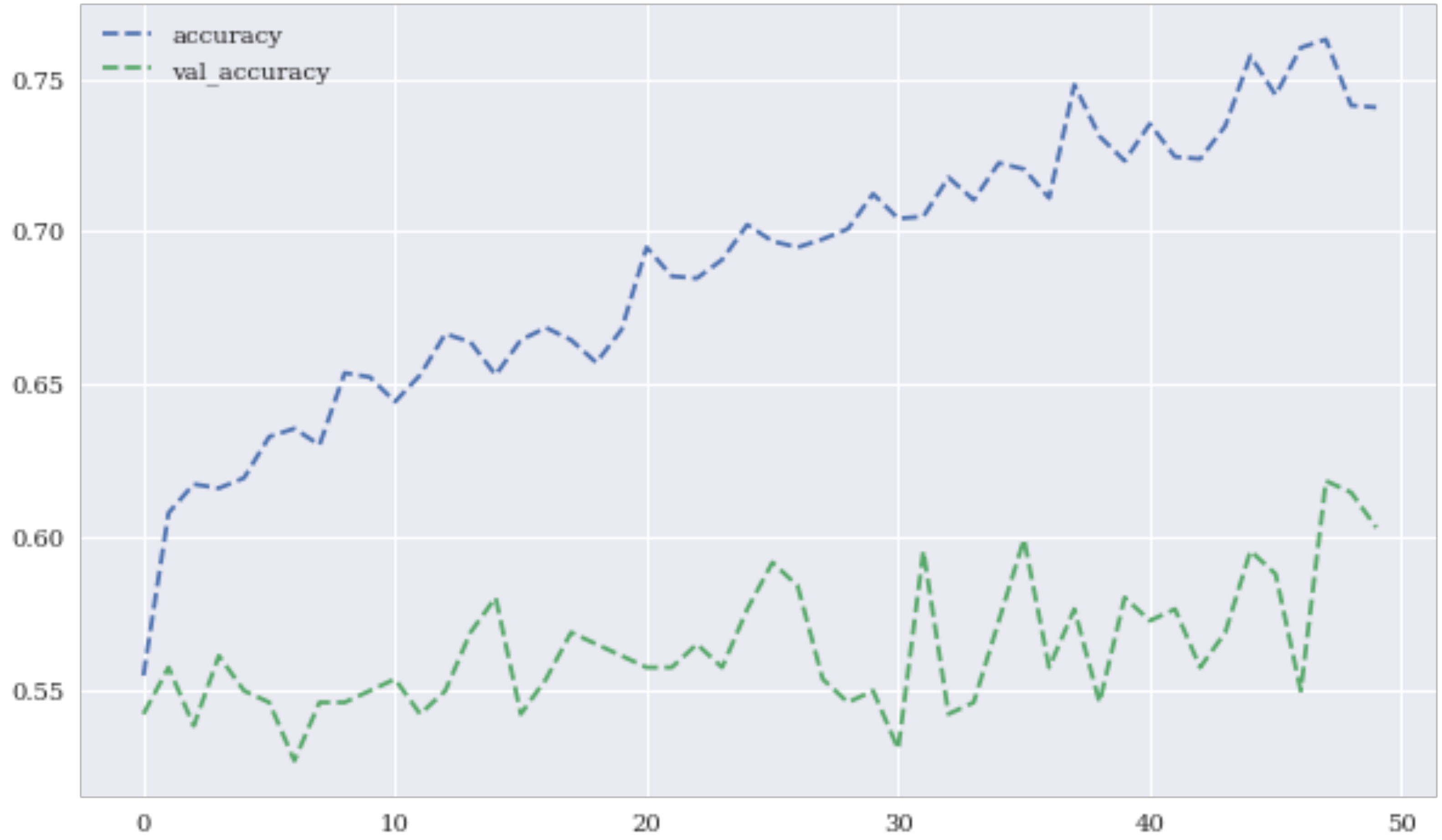

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Training and validation accuracy values (normalized features data)



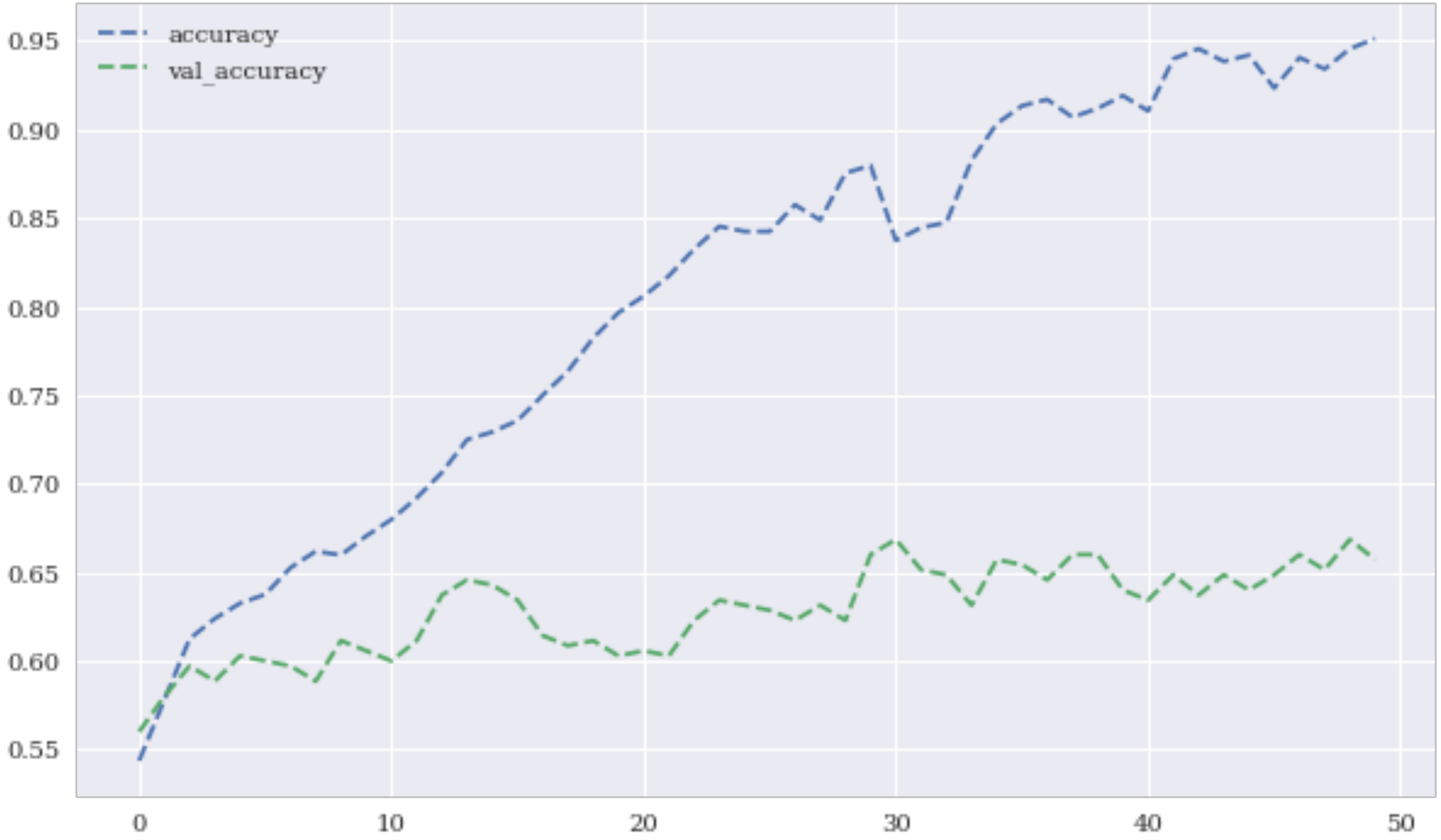

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Training and validation accuracy values (with dropout)




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Training and validation accuracy values (with regularization)




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Training and validation accuracy values (with dropout and regularization)

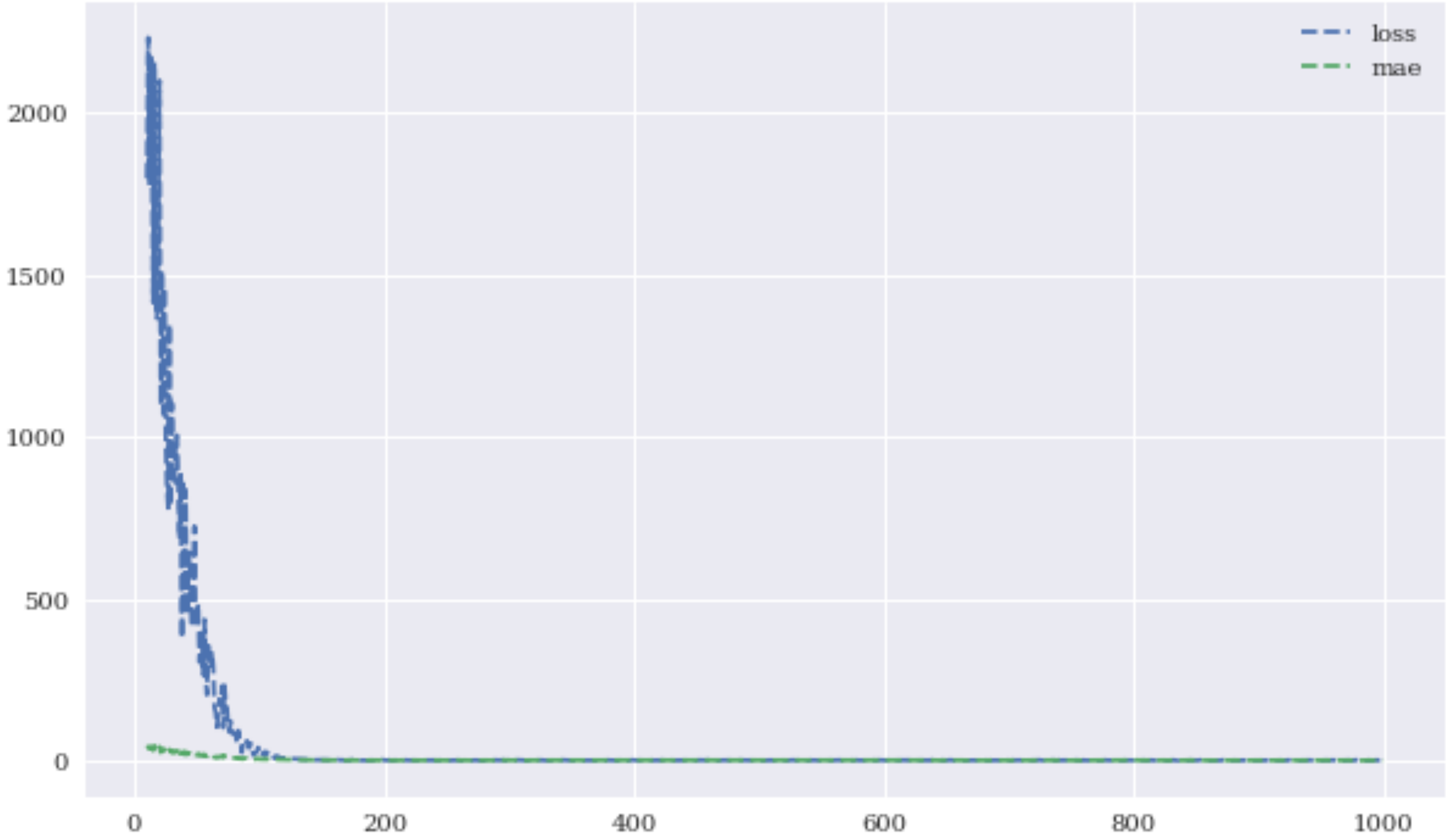

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

```python
from keras.models import Sequential
from keras.layers import SimpleRNN, LSTM, Dense

model = Sequential()
model.add(SimpleRNN(100, activation='relu',
            input_shape=(lags, 1)))
model.add(Dense(1, activation='linear'))
model.compile(optimizer='adagrad', loss='mse',
                metrics=['mae'])

model.summary()
```

```python
model.fit(g, epochs=1000, steps_per_epoch=5, verbose=False)
```

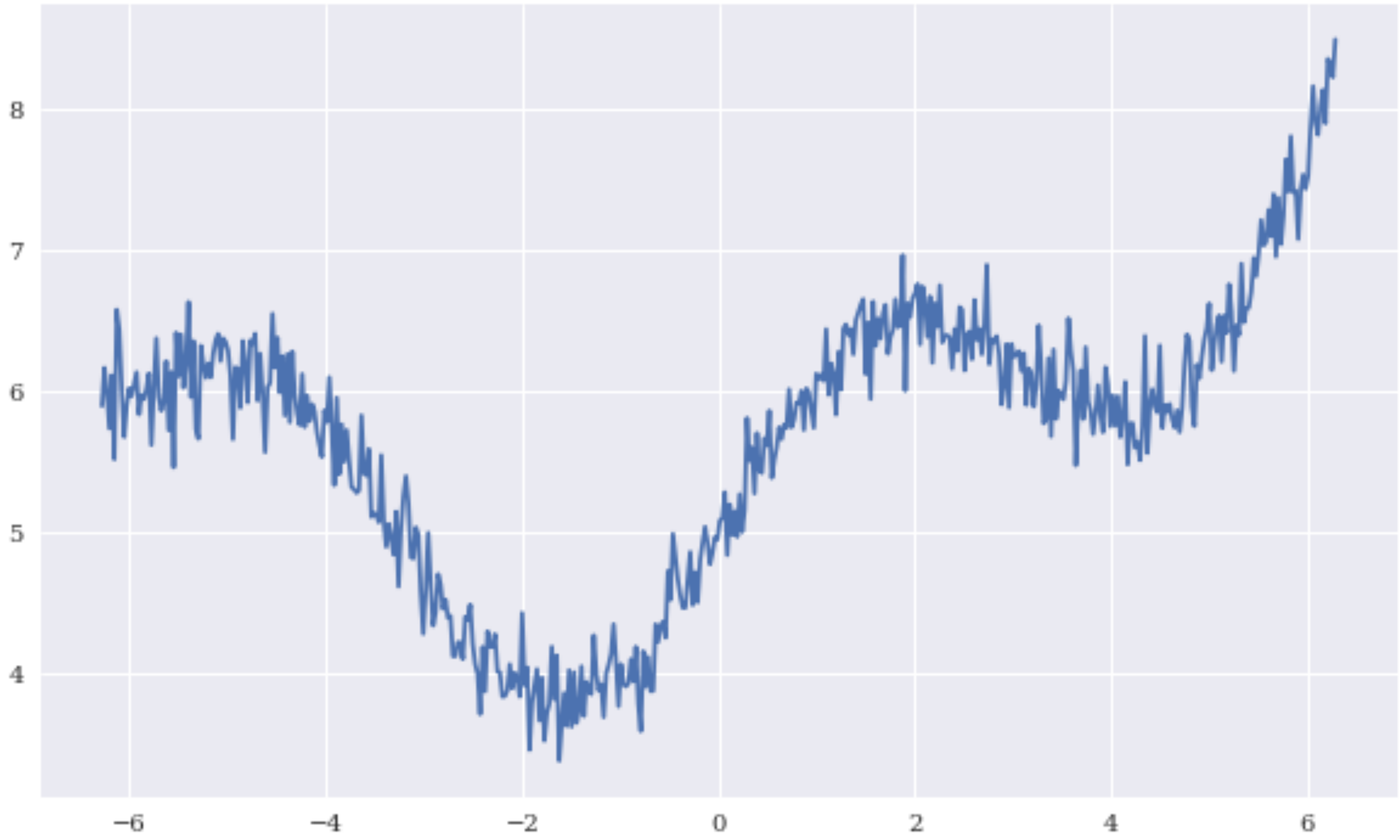
Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Performance metrics during RNN training



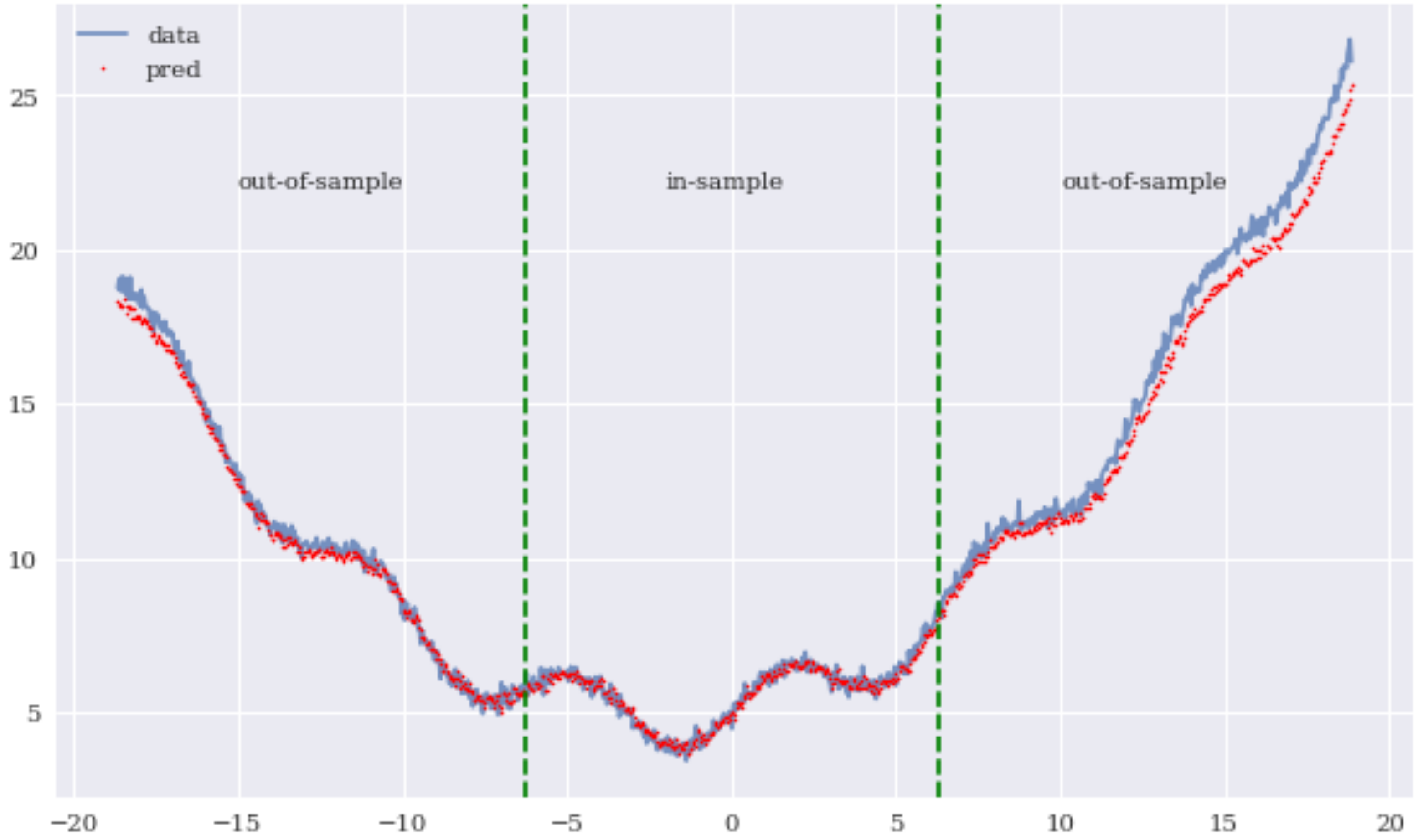

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Sample sequence data



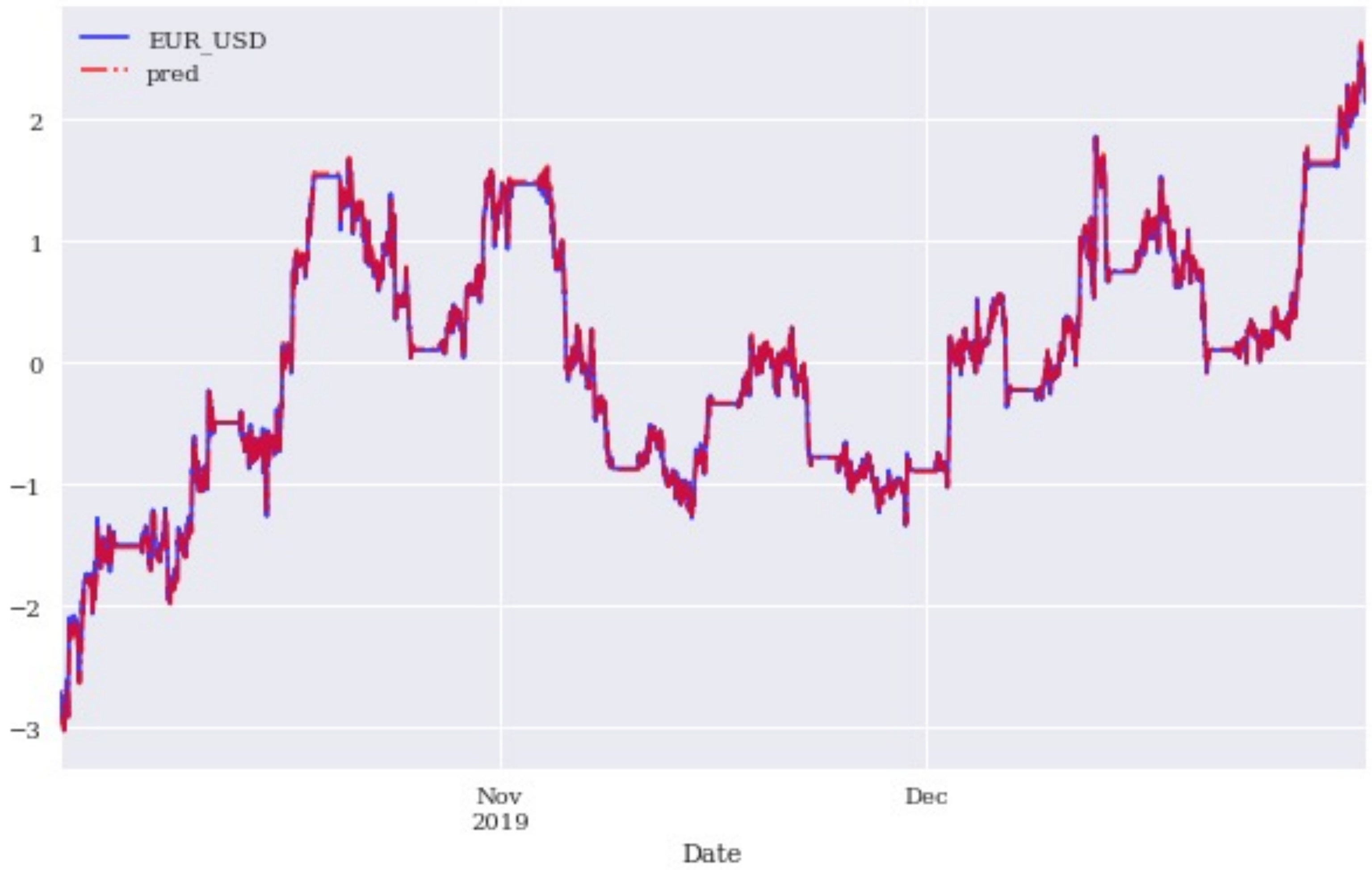

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# in-sample and out-of-sample predictions of the RNN



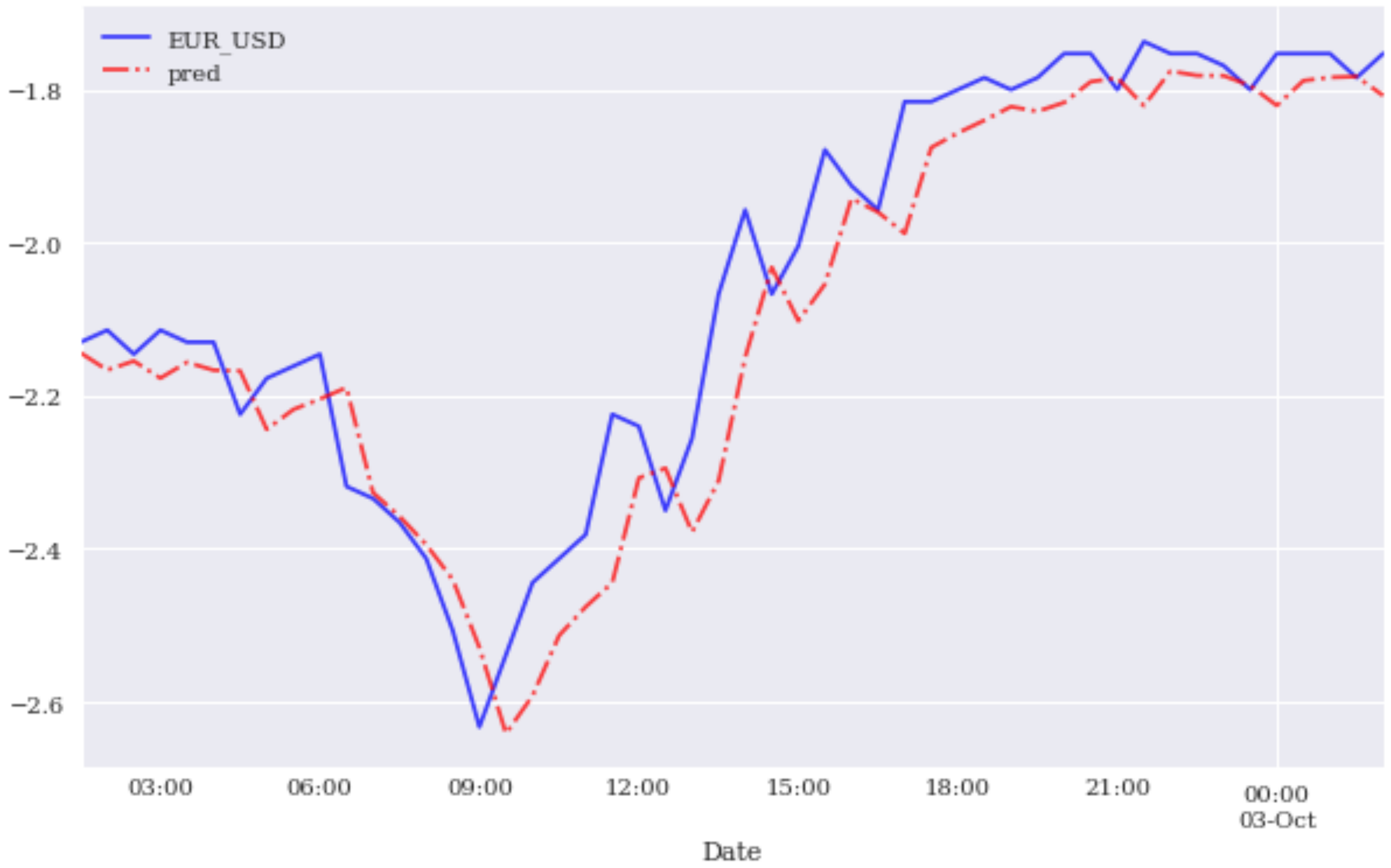

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# In-sample prediction for financial price series by the RNN (whole data set)




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# In-sample prediction for financial price series by the RNN (data sub-set)




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

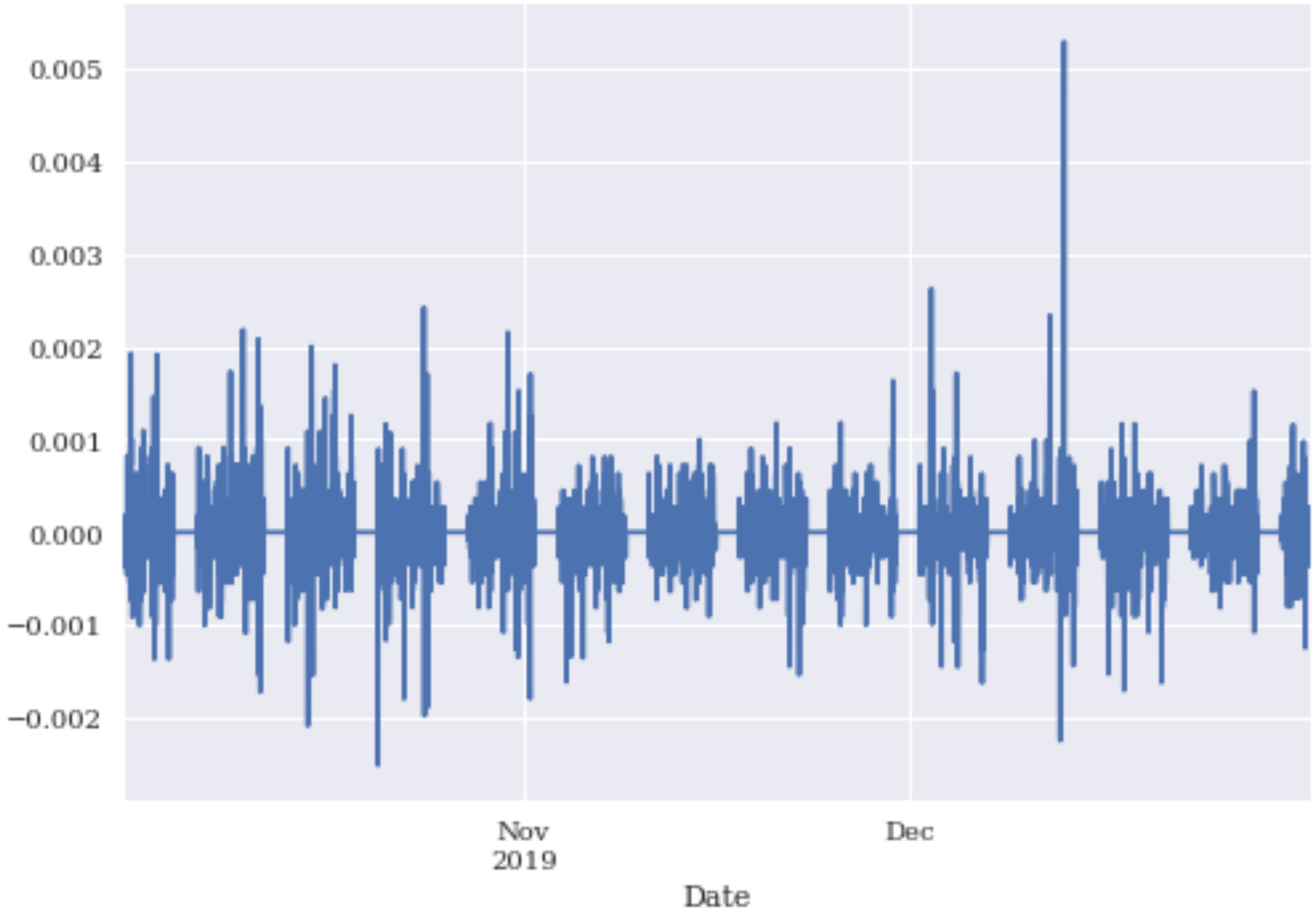
# Financial Price Series

```
data = generate_data()
data.plot()
```


Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Financial Return Series

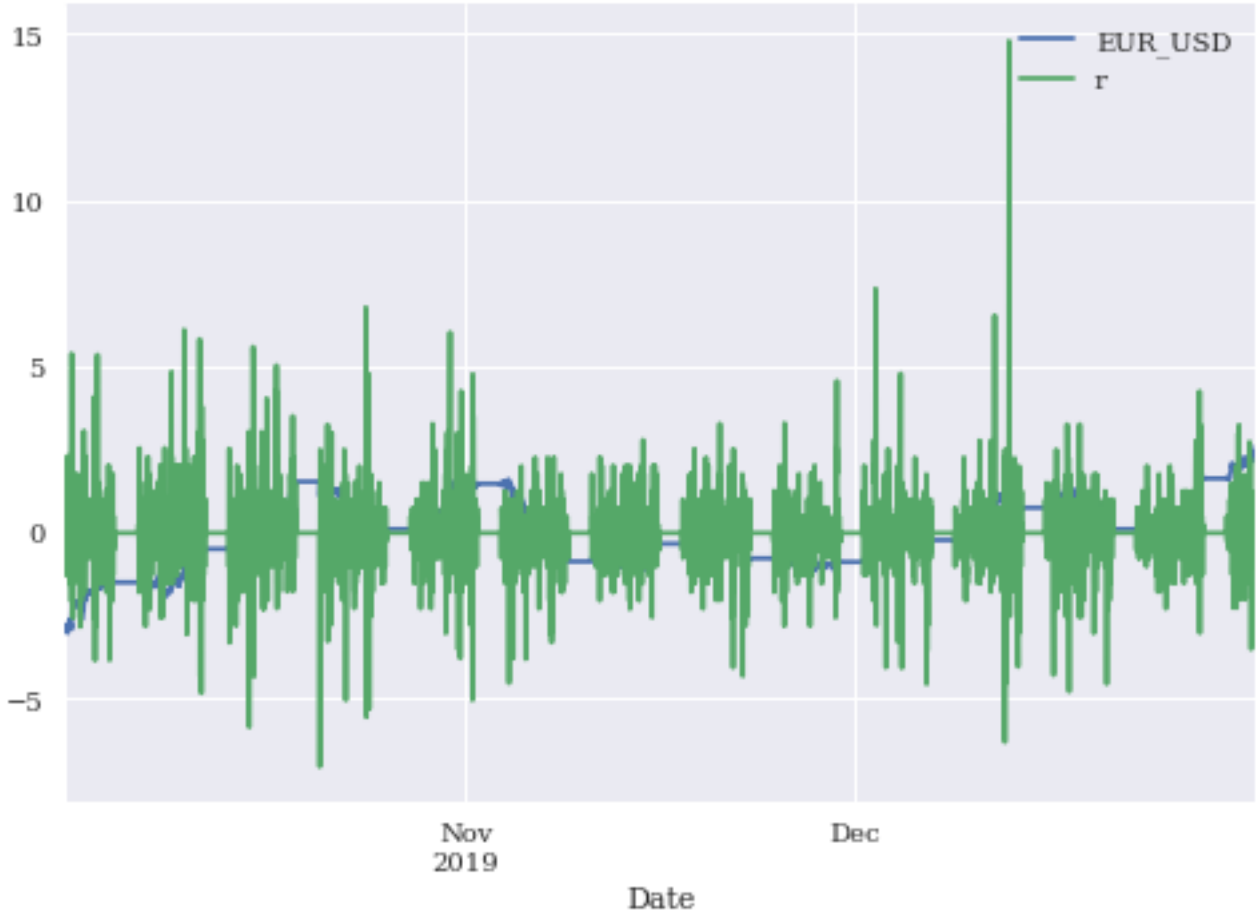
```
data['r'] = np.log(data / data.shift(1))
data['r'].plot()
```




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

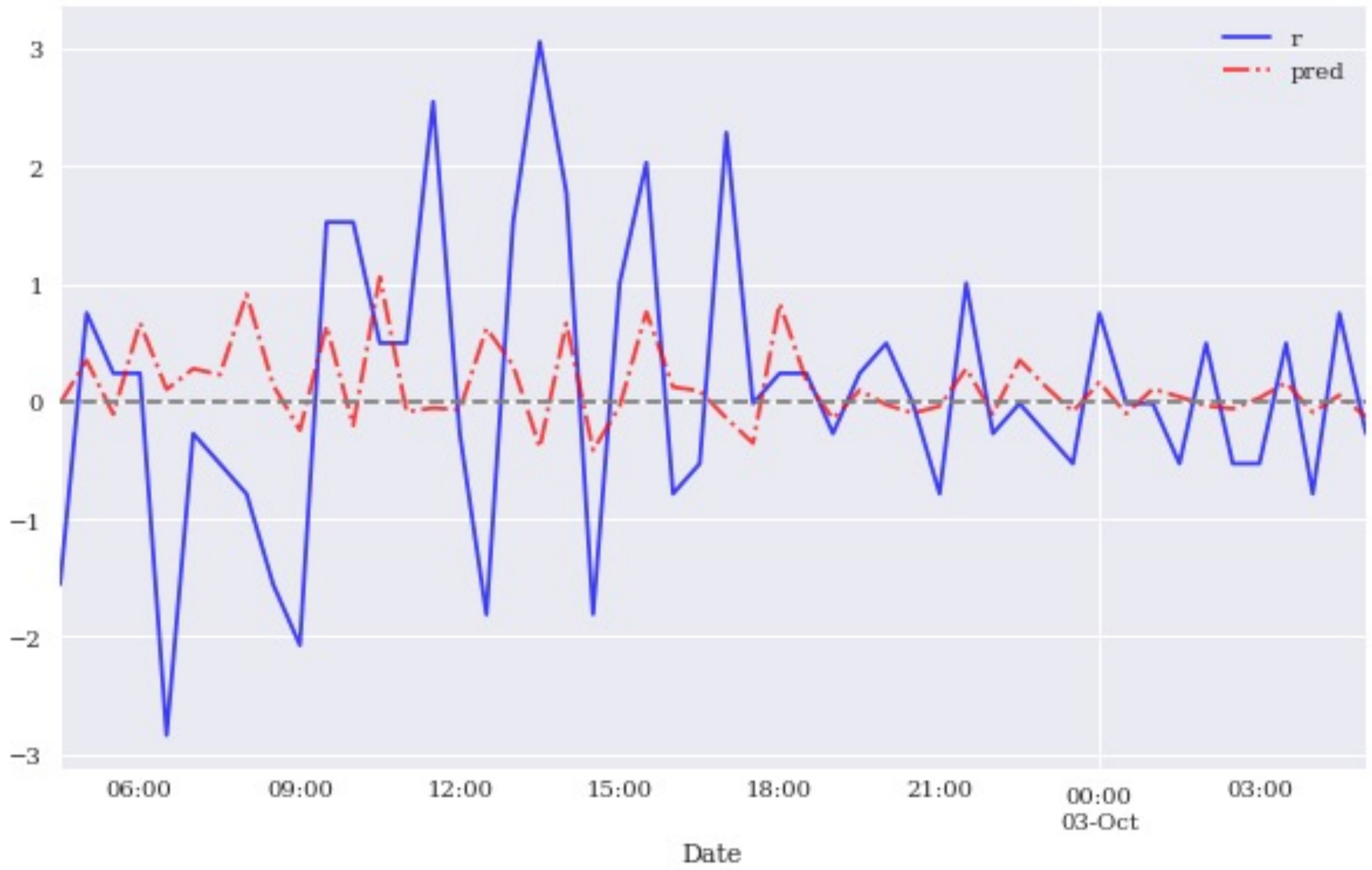
# Financial Price and Return Normalization Series

```
data.dropna(inplace=True)
data = (data - data.mean()) / data.std()
data.plot()
```




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# In-sample prediction for financial return series by the RNN (data sub-set)




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

```python
model = Sequential()
model.add(Conv1D(filters=96, kernel_size=5,
                 activation='relu',
                 input_shape=(len(cols), 1)))
model.add(Flatten())
model.add(Dense(10, activation='relu'))
model.add(Dense(1, activation='sigmoid'))

model.compile(optimizer='adam',
              loss='binary_crossentropy',
              metrics=['accuracy'])

model.summary()
```

```python
model.fit(np.atleast_3d(train[cols]), train['d'],
          epochs=60, batch_size=48, verbose=False,
          validation_split=0.15, shuffle=False)
```

# Performance metrics for the training and validation of the CNN


Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Gross performance of passive benchmark investment and CNN strategy (before/after transaction costs)

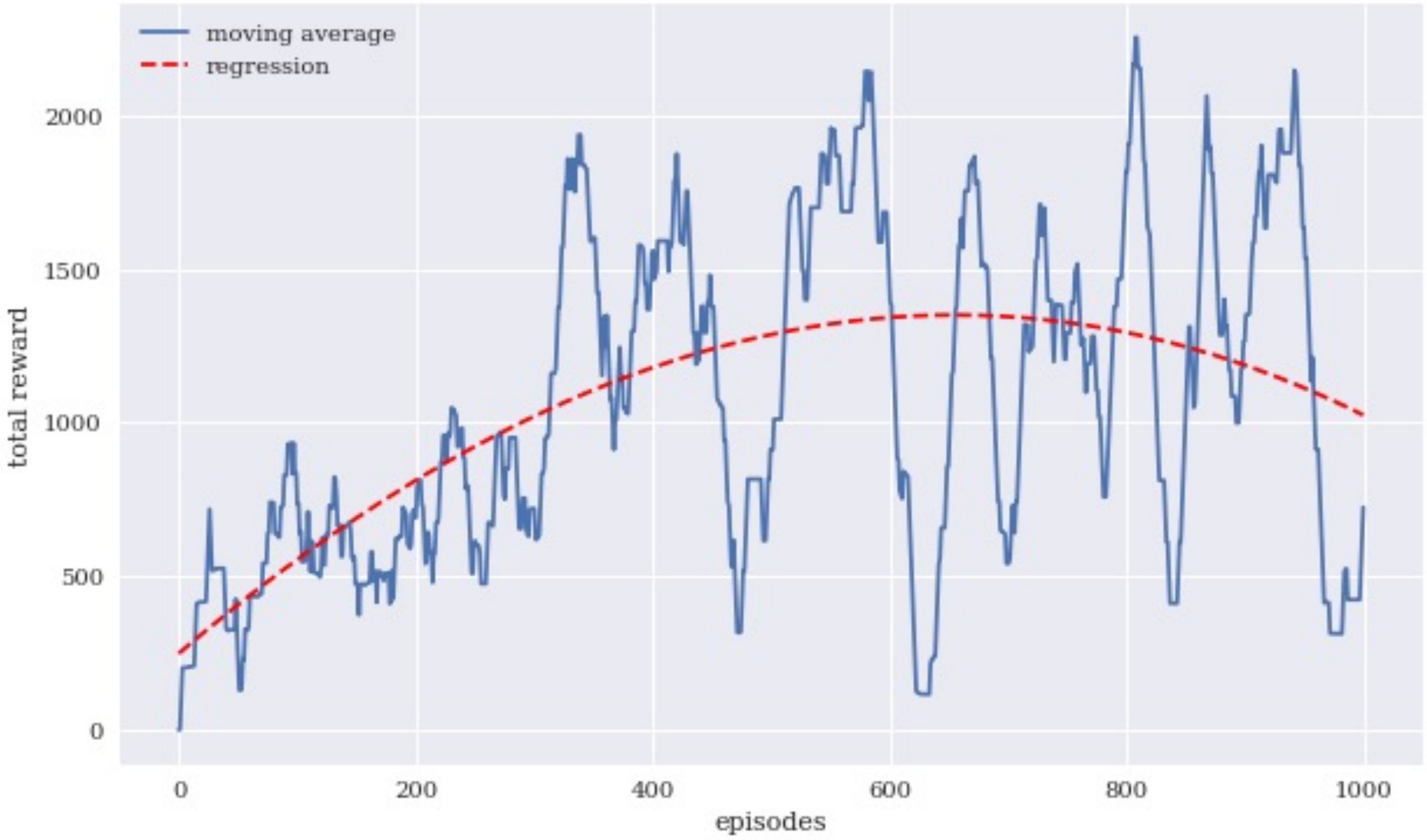

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O’Reilly Media.

# Reinforcement Learning in Finance

- Simple Learning
- DNN Learning
- Q Learning
- Finance Environment
- Improved Finance Environment
- Improved Financial QL Agent

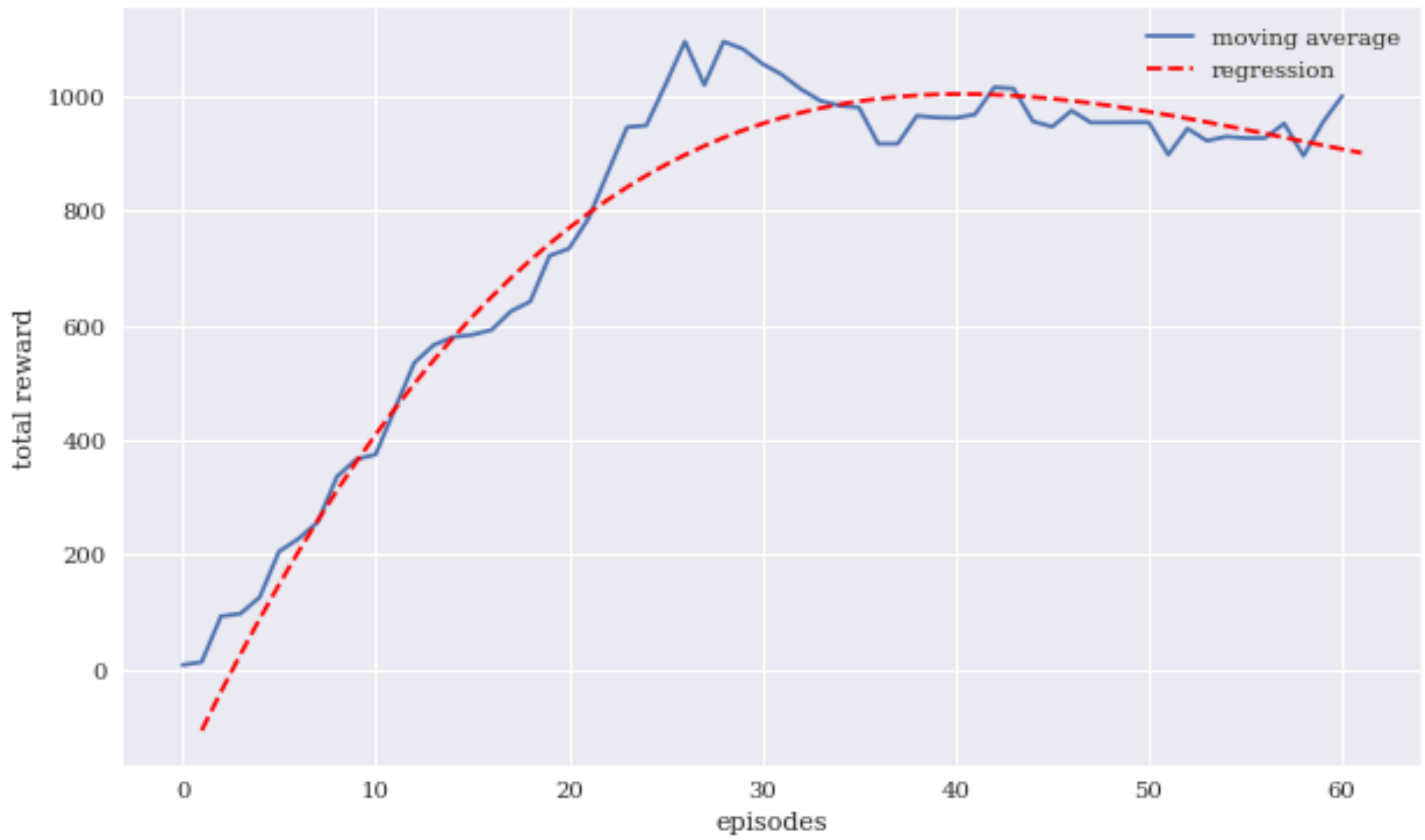
Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O’Reilly Media.

# Average total rewards of DQLAgent for CartPole



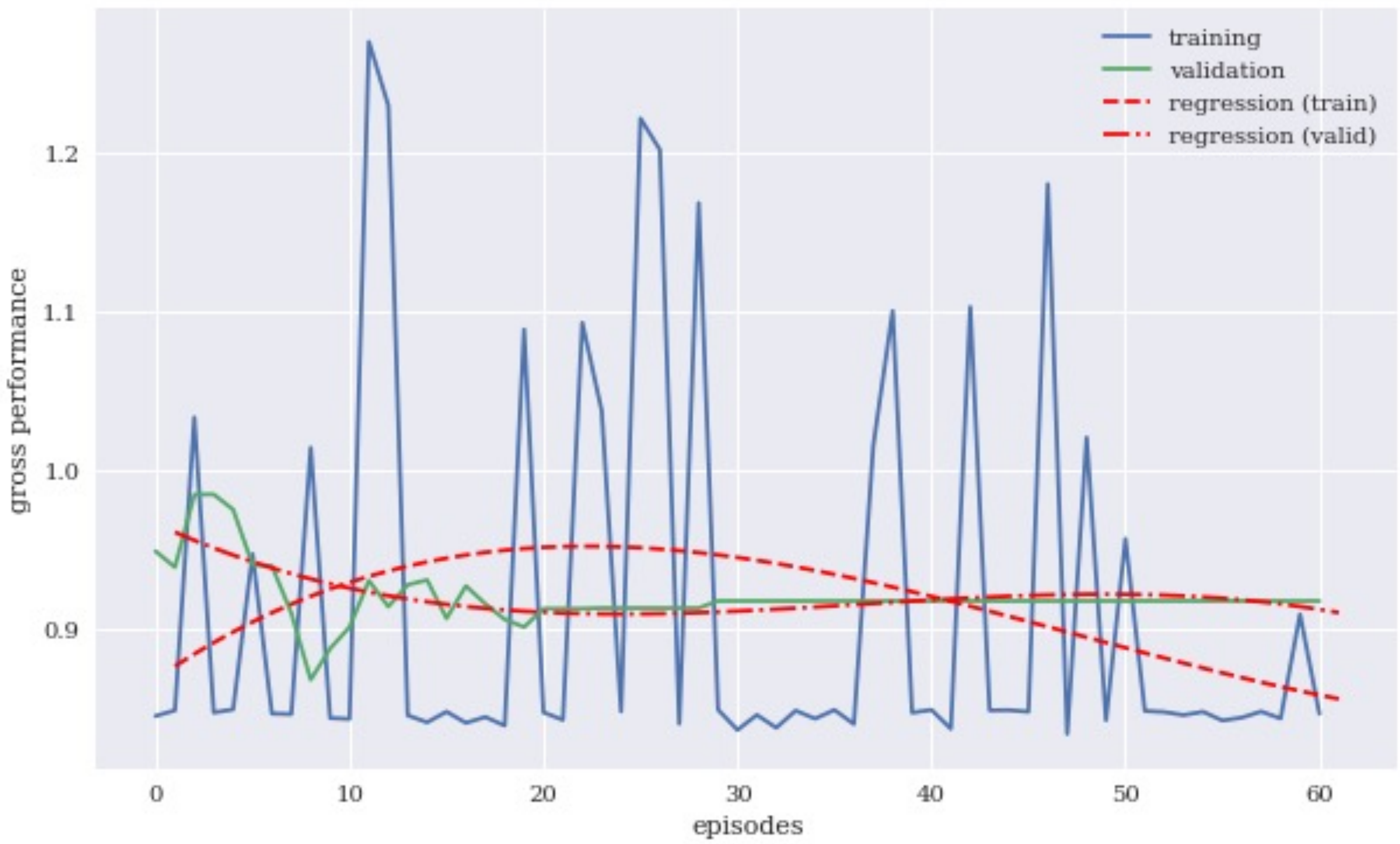

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Average total rewards of DQLAgent for Finance



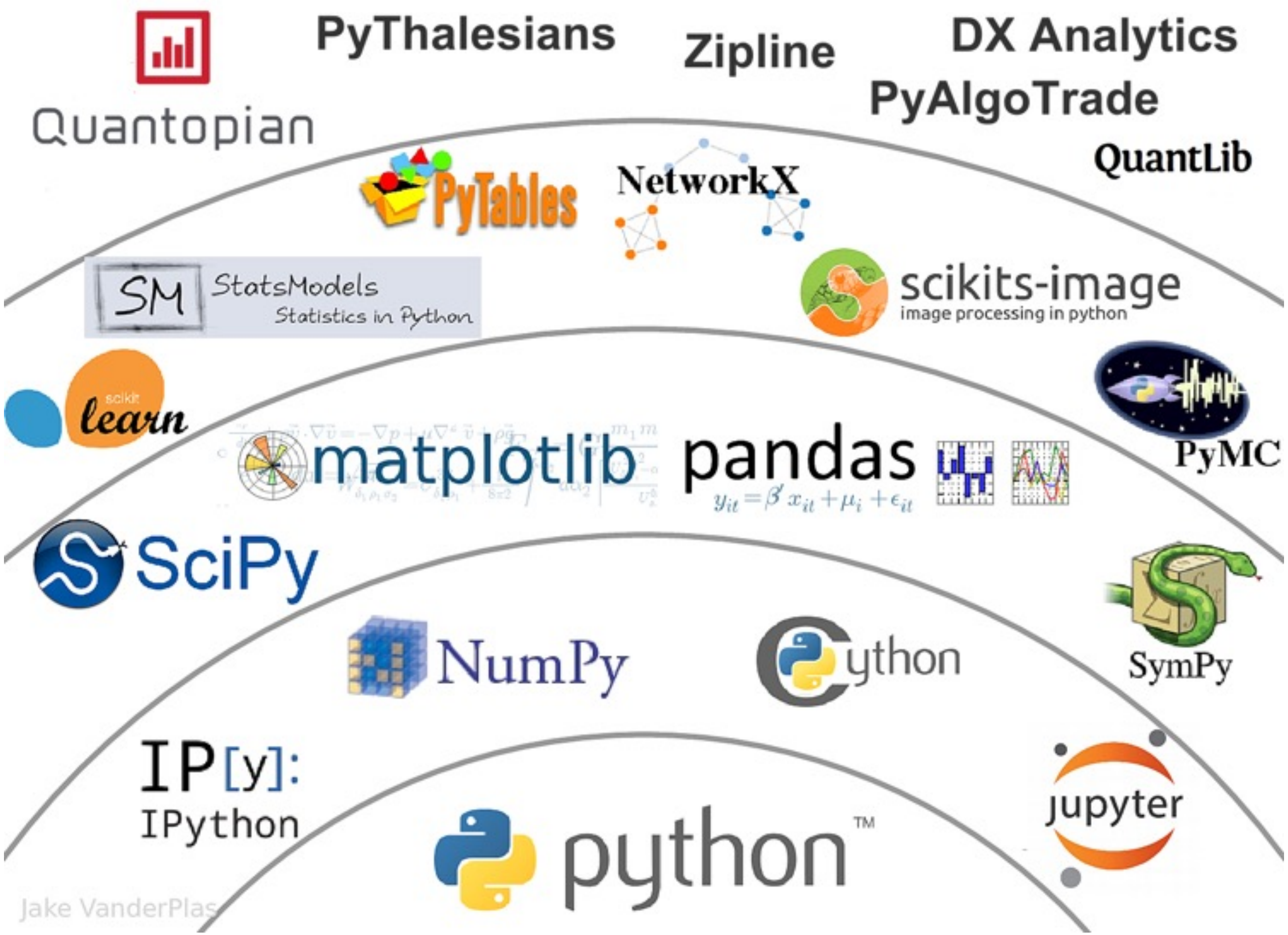

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# Training and validation performance of the FQLAgent per episode




Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# The Quant Finance PyData Stack

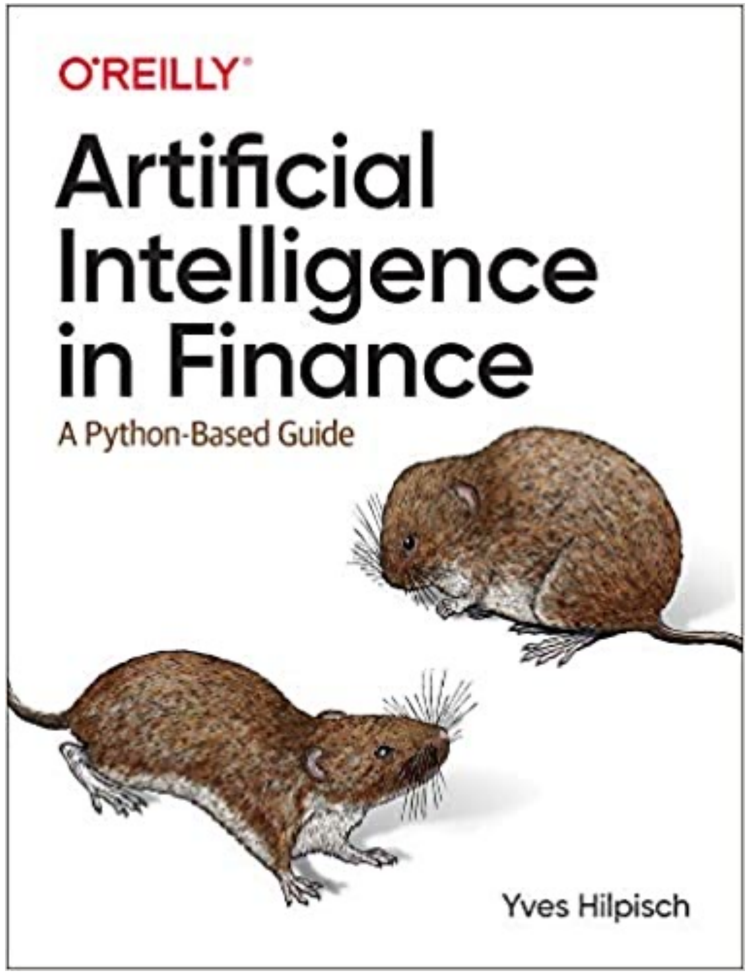



Source: http://nbviewer.jupyter.org/format/slides/github/quantopian/pyfolio/blob/master/pyfolio/examples/overview_slides.ipynb#/5

# Yves Hilpisch (2020),

# Artificial Intelligence in Finance: A Python-Based Guide,

O'Reilly




Source: https://www.amazon.com/Artificial-Intelligence-Finance-Python-Based-Guide/dp/1492055433

# Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly

yhilpisch / aiif Public

https://github.com/yhilpisch/aiif

Notifications | Star 98 | Fork 77

Code | Issues | Pull requests | Actions | Projects | Wiki | Security | Insights

main | 1 branch | 0 tags | Go to file | Code

**yves** Code updates for TF 2.3. e334251 on Dec 8, 2020 | 4 commits

| | | |
|---|---|---|
| code | Code updates for TF 2.3. | 11 months ago |
| .gitignore | Code updates for TF 2.3. | 11 months ago |
| LICENSE.txt | Code updates. | 11 months ago |
| README.md | Code updates. | 11 months ago |

README.md

## Artificial Intelligence in Finance

### About this Repository

This repository provides Python code and Jupyter Notebooks accompanying the **Artificial Intelligence in Finance** book published by O'Reilly.

O'REILLY

**About**

Jupyter Notebooks and code for the book Artificial Intelligence in Finance (O'Reilly) by Yves Hilpisch.

home.tpq.io/books/aiif

Readme

View license

**Releases**

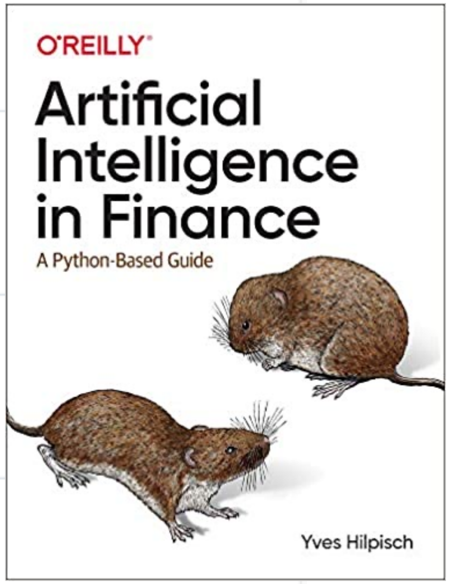
No releases published

**Packages**

No packages published

**Languages**

Jupyter Notebook 97.4% Python 2.6%




Source: https://github.com/yhilpisch/aiif

# Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly

yhilpisch / aiif Public

Notifications | Star 98 | Fork 77

Code | Issues | Pull requests | Actions | Projects | Wiki | Security | Insights

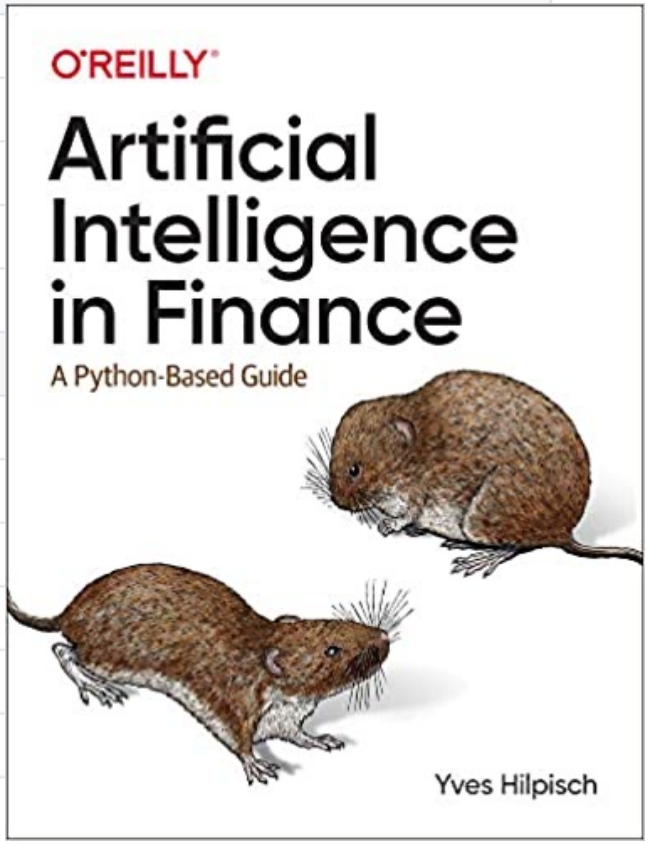
main | aiif / code /

https://github.com/yhilpisch/aiif/tree/main/code

Go to file

yves Code updates for TF 2.3. — e334251 on Dec 8, 2020 — History

| | |
|---|---|
| .. | |
| oanda | Code updates for TF 2.3. |
| 01_artificial_intelligence.ipynb | Code updates for TF 2.3. |
| 02_superintelligence.ipynb | Code updates for TF 2.3. |
| 03_normative_finance.ipynb | Code updates for TF 2.3. |
| 04_data_driven_finance_a.ipynb | Initial commit. |
| 04_data_driven_finance_b.ipynb | Initial commit. |
| 05_machine_learning.ipynb | Code updates for TF 2.3. |
| 06_ai_first_finance.ipynb | Code updates for TF 2.3. |
| 07_dense_networks.ipynb | Code updates for TF 2.3. |
| 08_recurrent_networks.ipynb | Code updates for TF 2.3. |
| 09_reinforcement_learning_a.ipynb | Code updates. |
| 09_reinforcement_learning_b.ipynb | Code updates for TF 2.3. |




Source: https://github.com/yhilpisch/aiif/tree/main/code

# Python in Google Colab (Python101)

https://colab.research.google.com/drive/1FEG6DnGvwfUbeo4zJ1zTunjMqf2RkCrT

python101.ipynb - Colaboratory

https://colab.research.google.com/drive/1FEG6DnGvwfUbeo4zJ1zTunjMqf2RkCrT?authuser=2#scrollTo=wsh36fLxDKC3

python101.ipynb

File Edit View Insert Runtime Tools Help

COMMENT SHARE

CODE TEXT CELL CELL CONNECTED EDITING

```python
# Future Value
pv = 100
r = 0.1
n = 7
fv = pv * ((1 + (r)) ** n)
print(round(fv, 2))
```

194.87

[11]
```python
amount = 100
interest = 10 #10% = 0.01 * 10
years = 7

future_value = amount * ((1 + (0.01 * interest)) ** years)
print(round(future_value, 2))
```

194.87

[12]
```python
# Python Function def
def getfv(pv, r, n):
    fv = pv * ((1 + (r)) ** n)
    return fv
fv = getfv(100, 0.1, 7)
print(round(fv, 2))
```

194.87

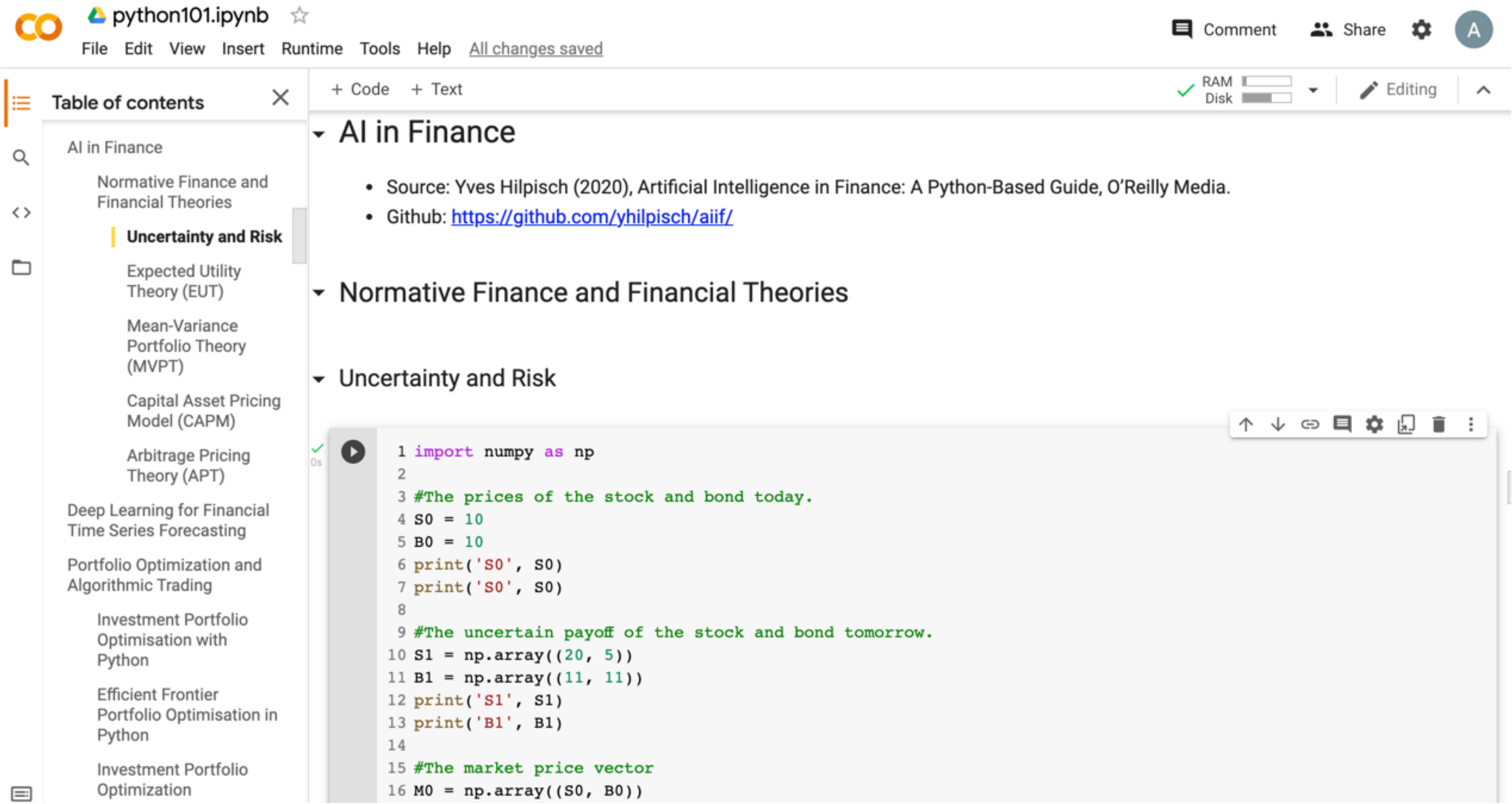
[13]
```python
# Python if else
score = 80
if score >=60 :
    print("Pass")
else:
    print("Fail")
```

Pass

https://tinyurl.com/aintpupython101

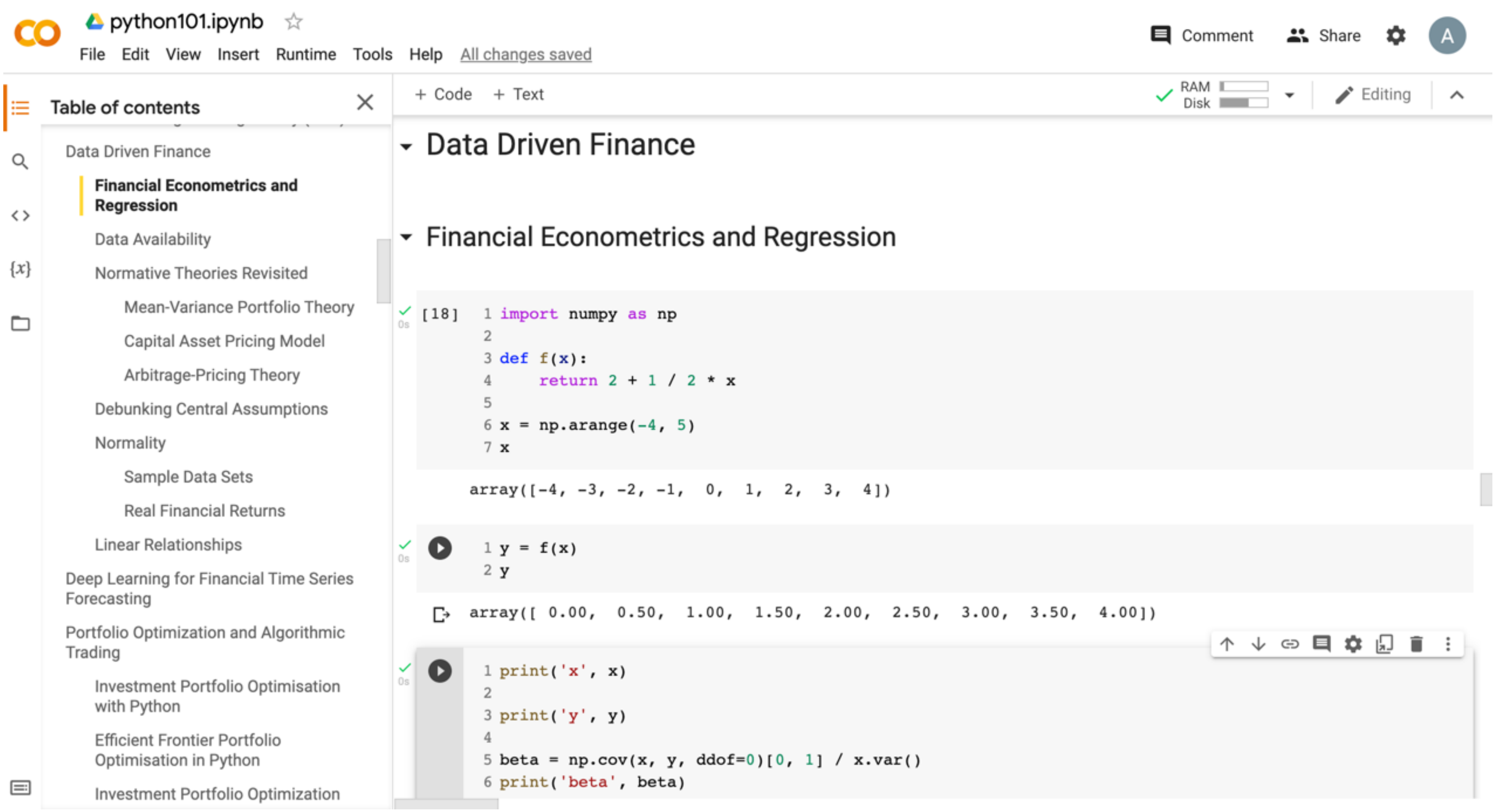
# Python in Google Colab (Python101)

https://colab.research.google.com/drive/1FEG6DnGvwfUbeo4zJ1zTunjMqf2RkCrT



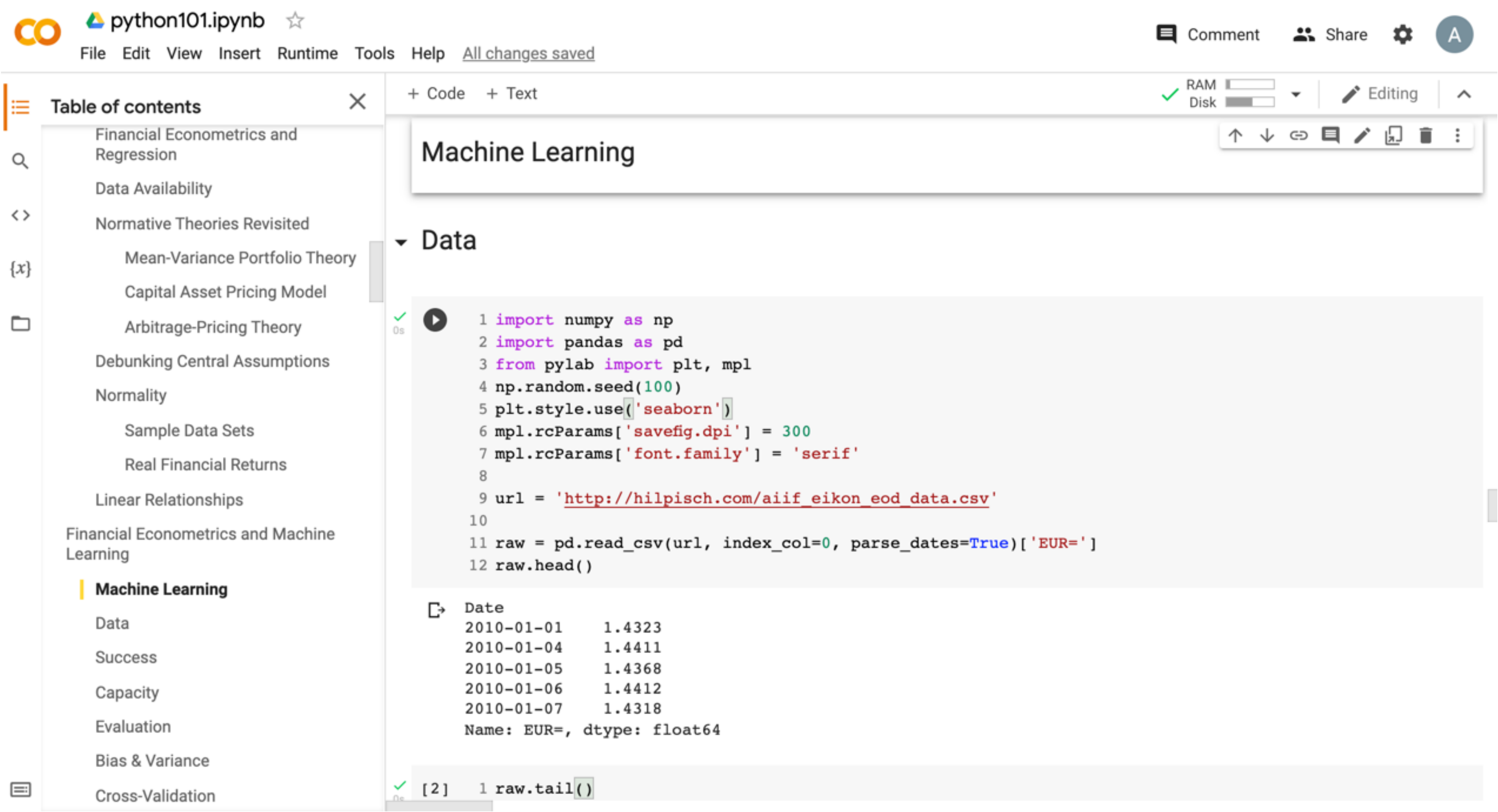

https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)



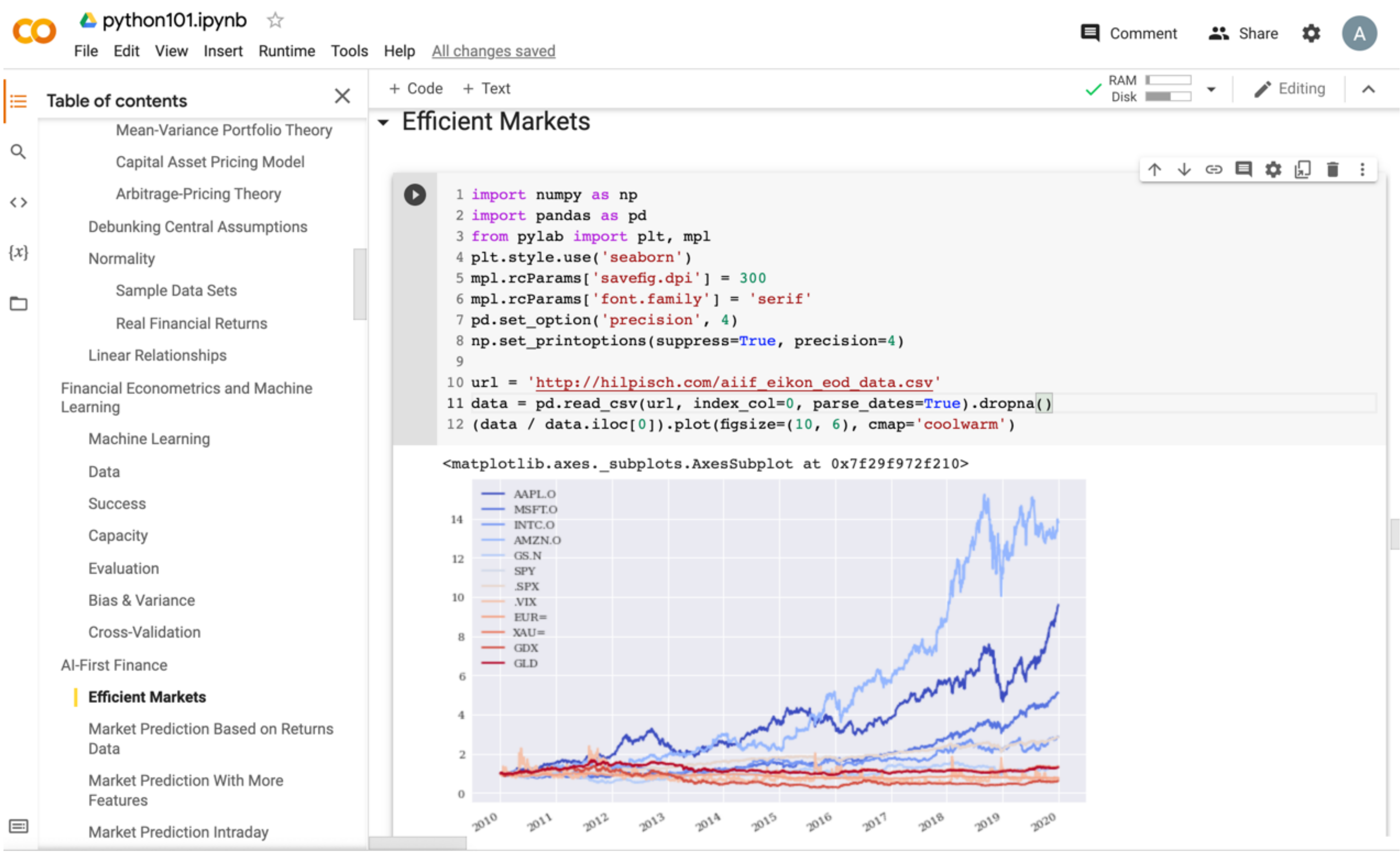

https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)




https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)




https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)

python101.ipynb

File Edit View Insert Runtime Tools Help All changes saved

Comment Share

+ Code + Text Connect Editing

Table of contents



## Deep Learning (DL) in Finance

- Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.
- Github: https://github.com/yhilpisch/aiif/

## Dense Neural Networks (DNN)

```
import os
import numpy as np
import pandas as pd
from pylab import plt, mpl
plt.style.use('seaborn')
mpl.rcParams['savefig.dpi'] = 300
mpl.rcParams['font.family'] = 'serif'
pd.set_option('precision', 4)
np.set_printoptions(suppress=True, precision=4)
os.environ['PYTHONHASHSEED'] = '0'
```

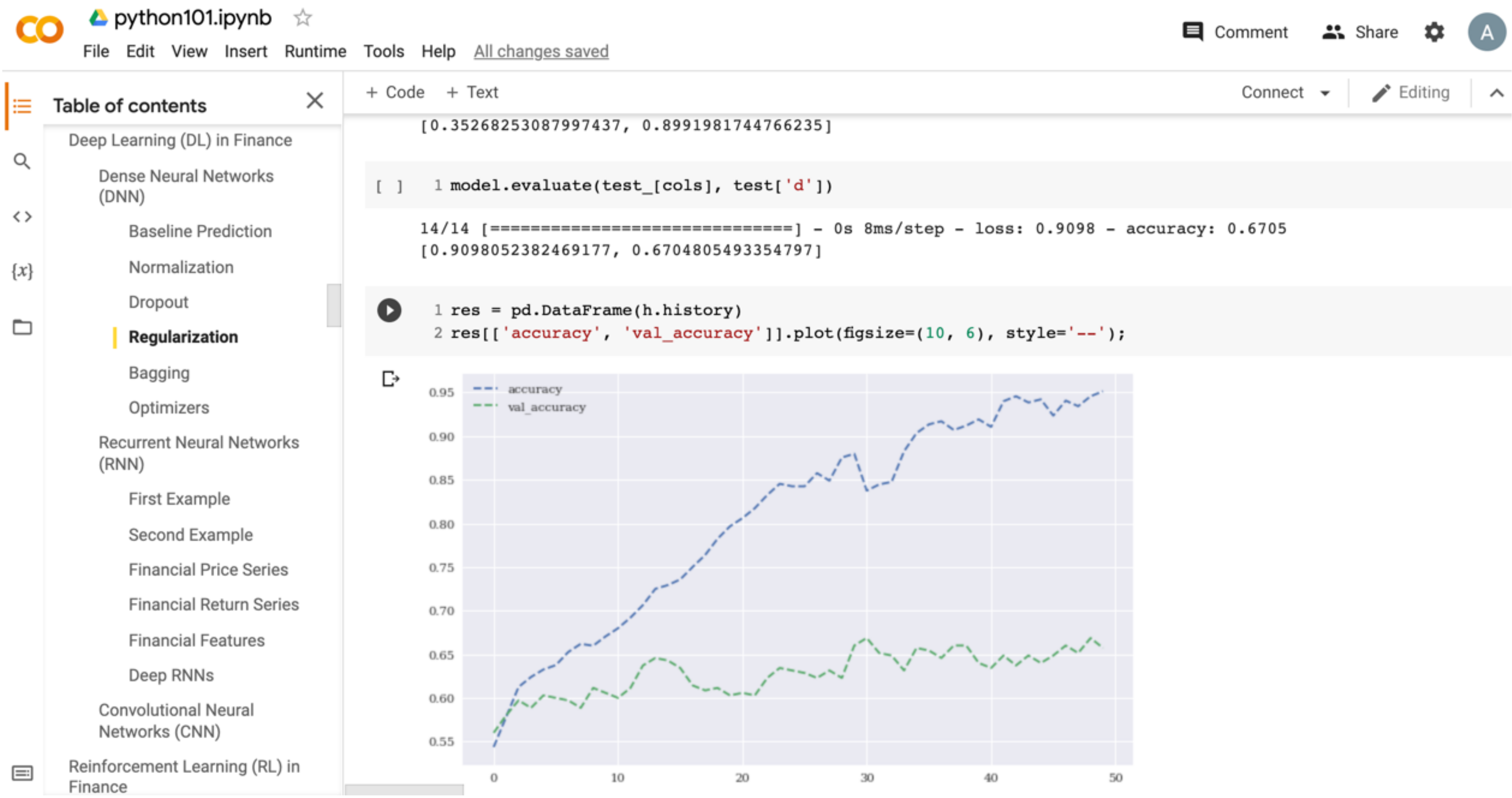
[ ]

```
url = 'http://hilpisch.com/aiif_eikon_id_eur_usd.csv'
symbol = 'EUR_USD'
raw = pd.read_csv(url, index_col=0, parse_dates=True)
raw.head()
```

| HIGH | LOW | OPEN | CLOSE |
|---|---|---|---|

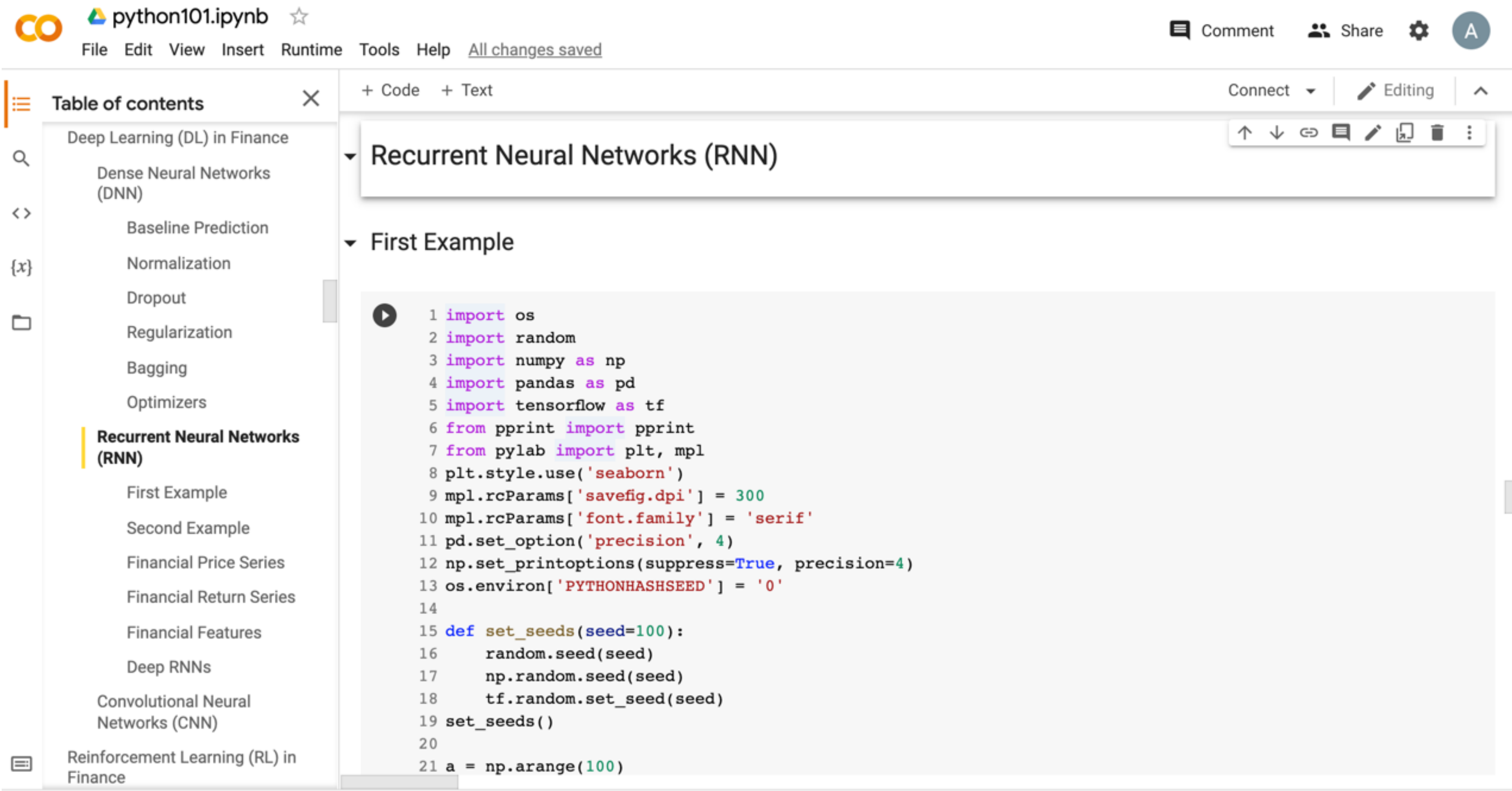
https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)




https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)




https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)

python101.ipynb

File Edit View Insert Runtime Tools Help Saving...

Comment Share

+ Code + Text Connect Editing

Table of contents

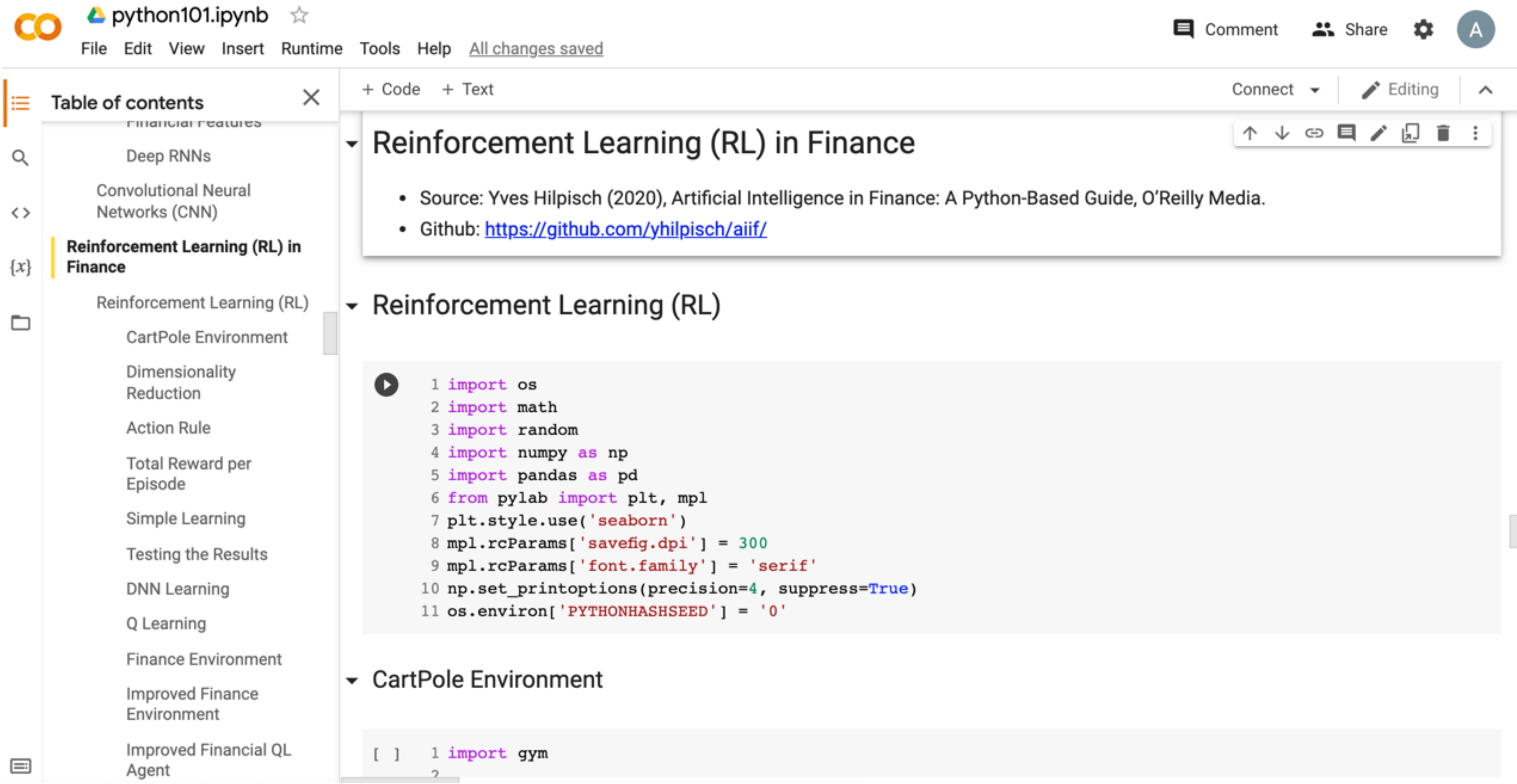


## Convolutional Neural Networks (CNN)

```python
import os
import math
import numpy as np
import pandas as pd
from pylab import plt, mpl
plt.style.use('seaborn')
mpl.rcParams['savefig.dpi'] = 300
mpl.rcParams['font.family'] = 'serif'
os.environ['PYTHONHASHSEED'] = '0'

url = 'http://hilpisch.com/aiif_eikon_eod_data.csv'
symbol = 'EUR='
data = pd.DataFrame(pd.read_csv(url, index_col=0,
                    parse_dates=True).dropna()[symbol])
data.info()
lags = 5
features = [symbol, 'r', 'd', 'sma', 'min', 'max', 'mom', 'vol']

def add_lags(data, symbol, lags, window=20, features=features):
    cols = []
    df = data.copy()
    df.dropna(inplace=True)
    df['r'] = np.log(df / df.shift(1))
    df['sma'] = df[symbol].rolling(window).mean()
    df['min'] = df[symbol].rolling(window).min()
```

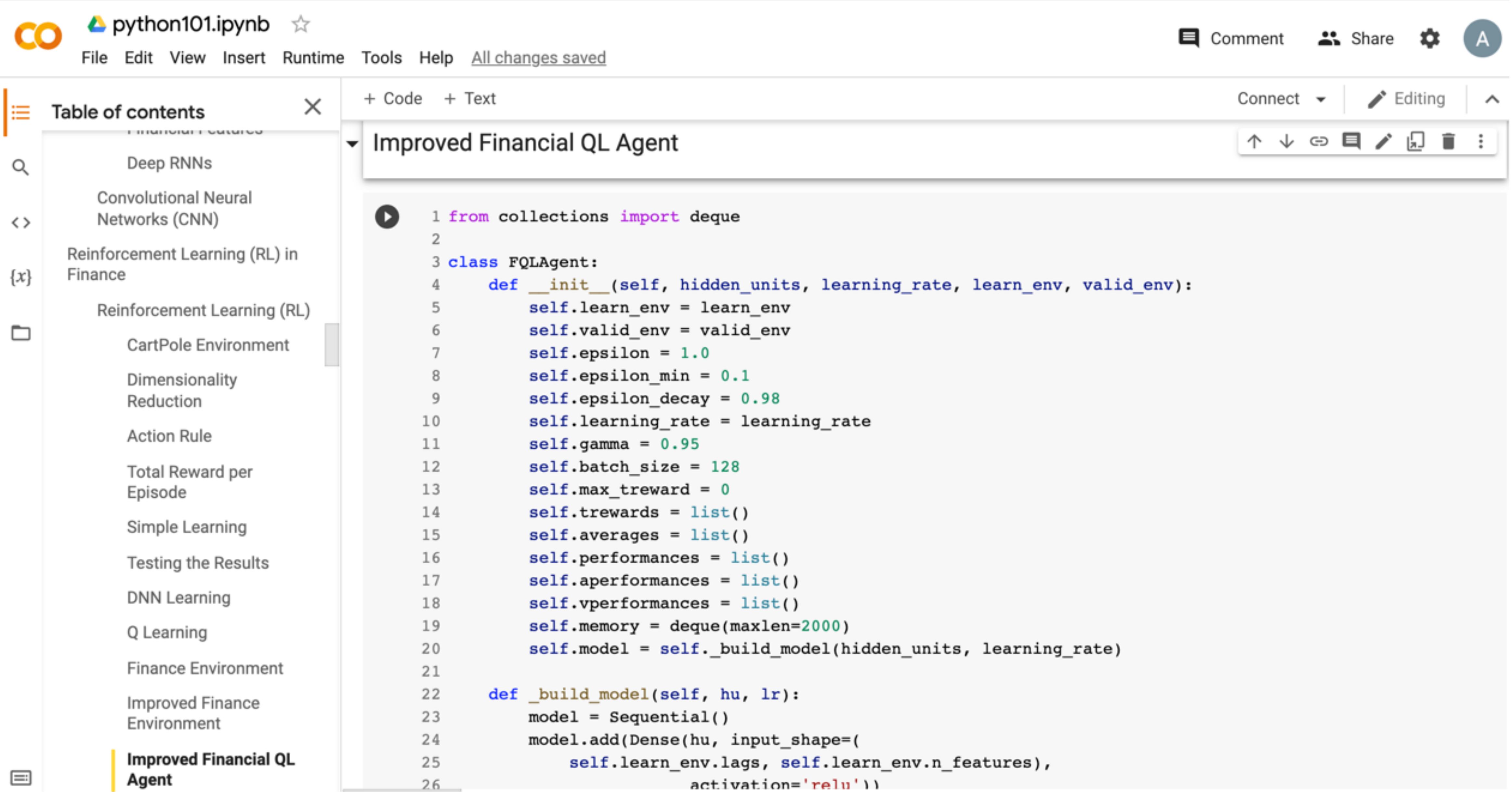
https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)




https://tinyurl.com/aintpupython101

# Python in Google Colab (Python101)




https://tinyurl.com/aintpupython101

# Summary

- Deep Learning (DL) in Finance
  - Dense Neural Networks (DNN)
  - Recurrent Neural Networks (RNN)
  - Convolutional Neural Networks (CNN)
- Reinforcement Learning (RL) in Finance
  - Q Learning (QL)
  - Improved Finance Environment
  - Improved Financial QL Agent

Source: Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O'Reilly Media.

# References


- Yves Hilpisch (2020), Artificial Intelligence in Finance: A Python-Based Guide, O’Reilly Media, https://github.com/yhilpisch/aiif .
- Aurélien Géron (2019), Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems, 2nd Edition, O’Reilly Media.
- Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey." Applied Soft Computing (2020): 106384.
- Omer Berat Sezer, Mehmet Ugur Gudelek, and Ahmet Murat Ozbayoglu (2020), "Financial time series forecasting with deep learning: A systematic literature review: 2005–2019." Applied Soft Computing 90 (2020): 106181.
- Min-Yuh Day (2022), Python 101, https://tinyurl.com/aintpupython101