



UNIVERSITY OF TECHNOLOGY
IN THE EUROPEAN CAPITAL OF CULTURE
CHEMNITZ

Neurocomputing

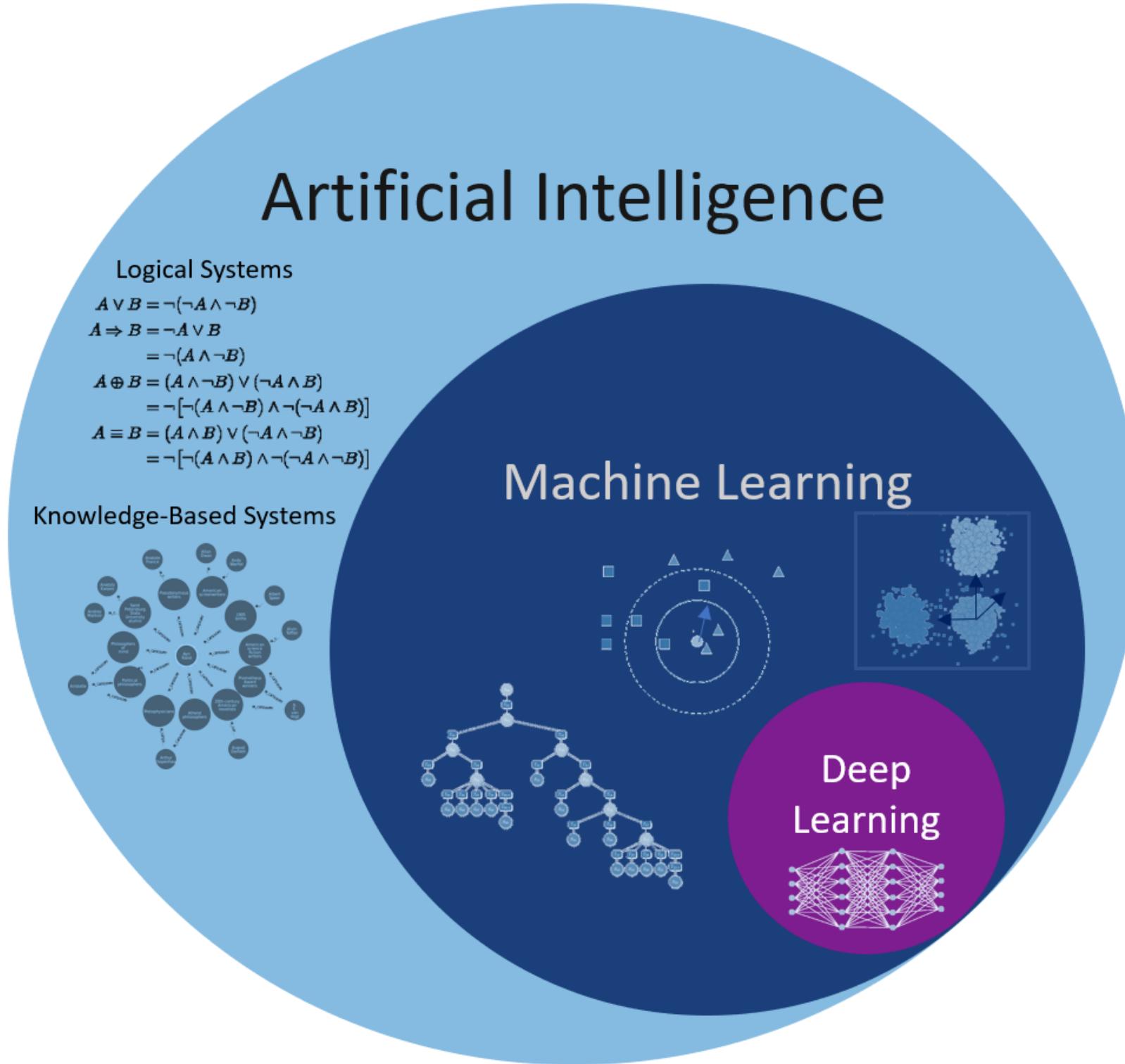
Introduction

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<https://tu-chemnitz.de/informatik/KI/edu/neurocomputing>

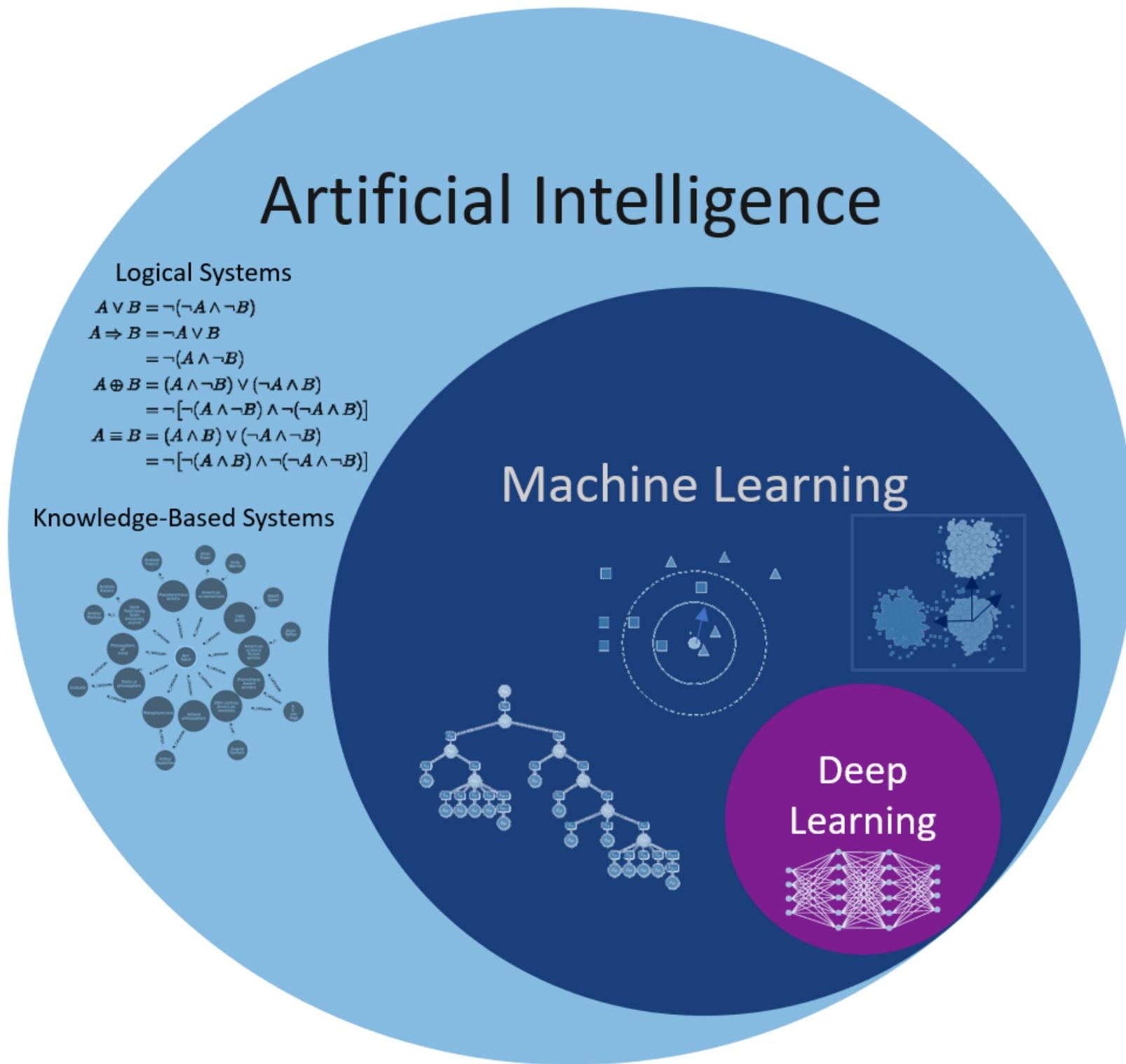
Artificial Intelligence, Machine Learning, Deep Learning, Neurocomputing



- The term **Artificial Intelligence** was coined by John McCarthy at the Dartmouth Summer Research Project on Artificial Intelligence in **1956**.
- *"The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it."*
- **Good old-fashion AI** approaches (GOFAI) were purely symbolic (logical systems, knowledge-based systems) or using linear neural networks.
- They were able to play checkers, prove mathematical theorems, make simple conversations (ELIZA), translate languages...

Source: <https://data-science-blog.com/blog/2018/05/14/machine-learning-vs-deep-learning-wie-liegt-der-unterschied>

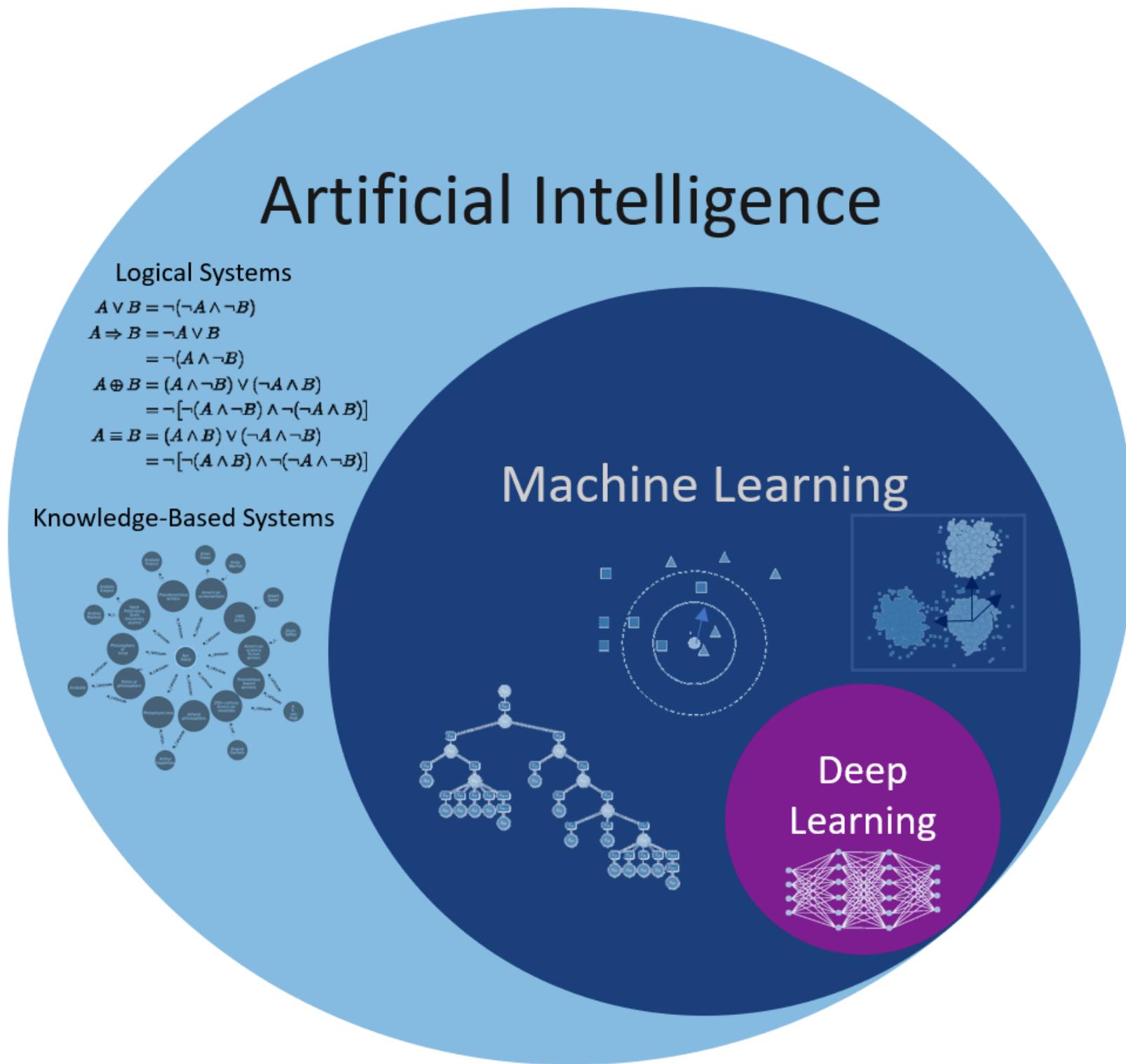
Artificial Intelligence, Machine Learning, Deep Learning, Neurocomputing



- **Machine learning (ML)** is a branch of AI that focuses on learning from examples (data-driven).
- ML algorithms include:
 - Neural Networks (multi-layer perceptrons)
 - Statistical analysis (Bayesian modeling, PCA)
 - Clustering algorithms (k-means, GMM, spectral clustering)
 - Support vector machines
 - Decision trees, random forests
- Other names: big data, data science, operational research, pattern recognition...

Source: <https://data-science-blog.com/blog/2018/05/14/machine-learning-vs-deep-learning-wie-liegt-der-unterschied>

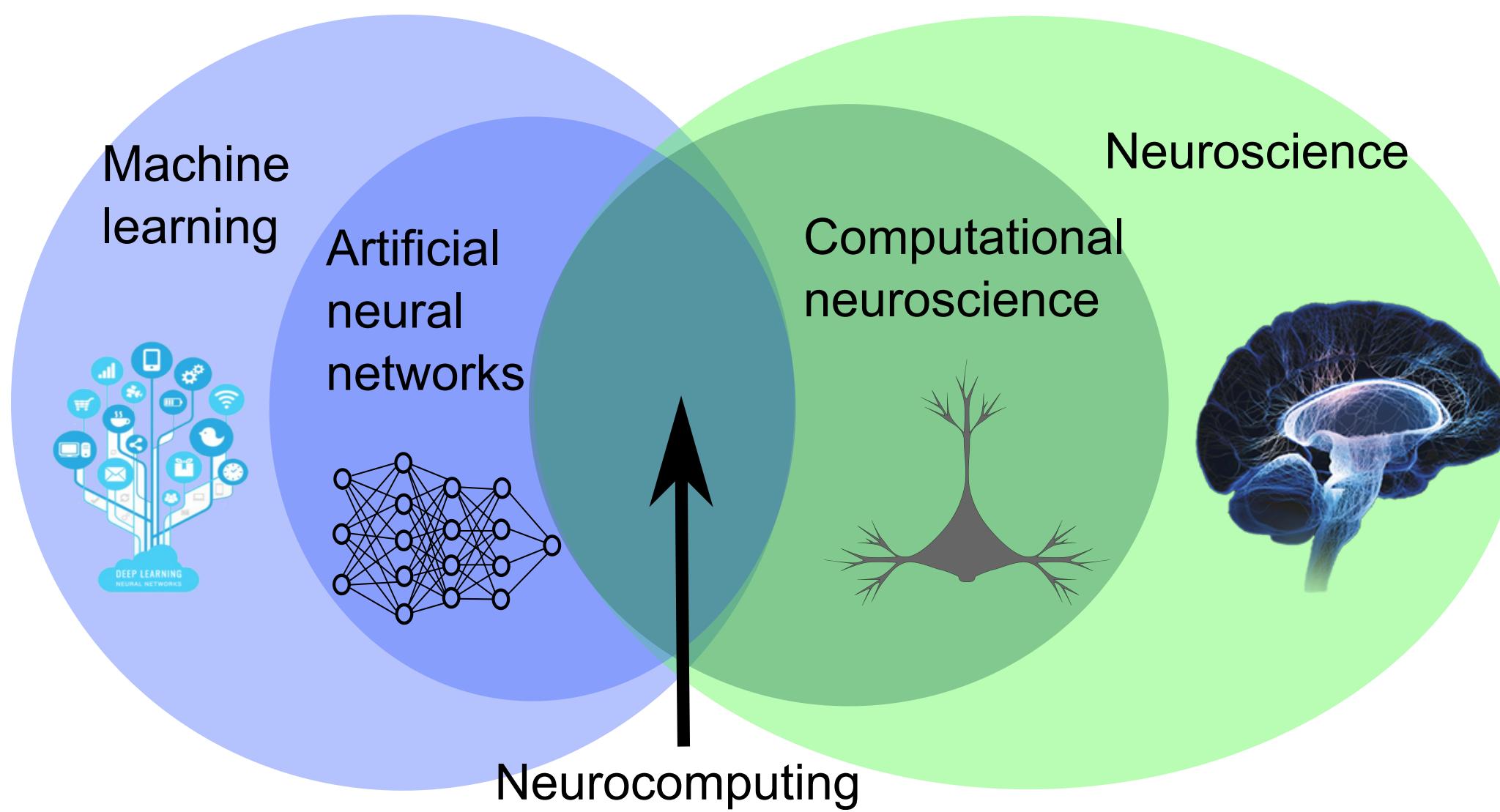
Artificial Intelligence, Machine Learning, Deep Learning, Neurocomputing



- **Deep Learning** is a recent re-branding of neural networks.
- Deep learning focuses on learning high-level representations of the data, using:
 - Deep neural networks (DNN)
 - Convolutional neural networks (CNN)
 - Recurrent neural networks (RNN)
 - Generative models (GAN, VAE)
 - Deep reinforcement learning (DQN, PPO, AlphaGo)
 - Transformers
 - Graph neural networks

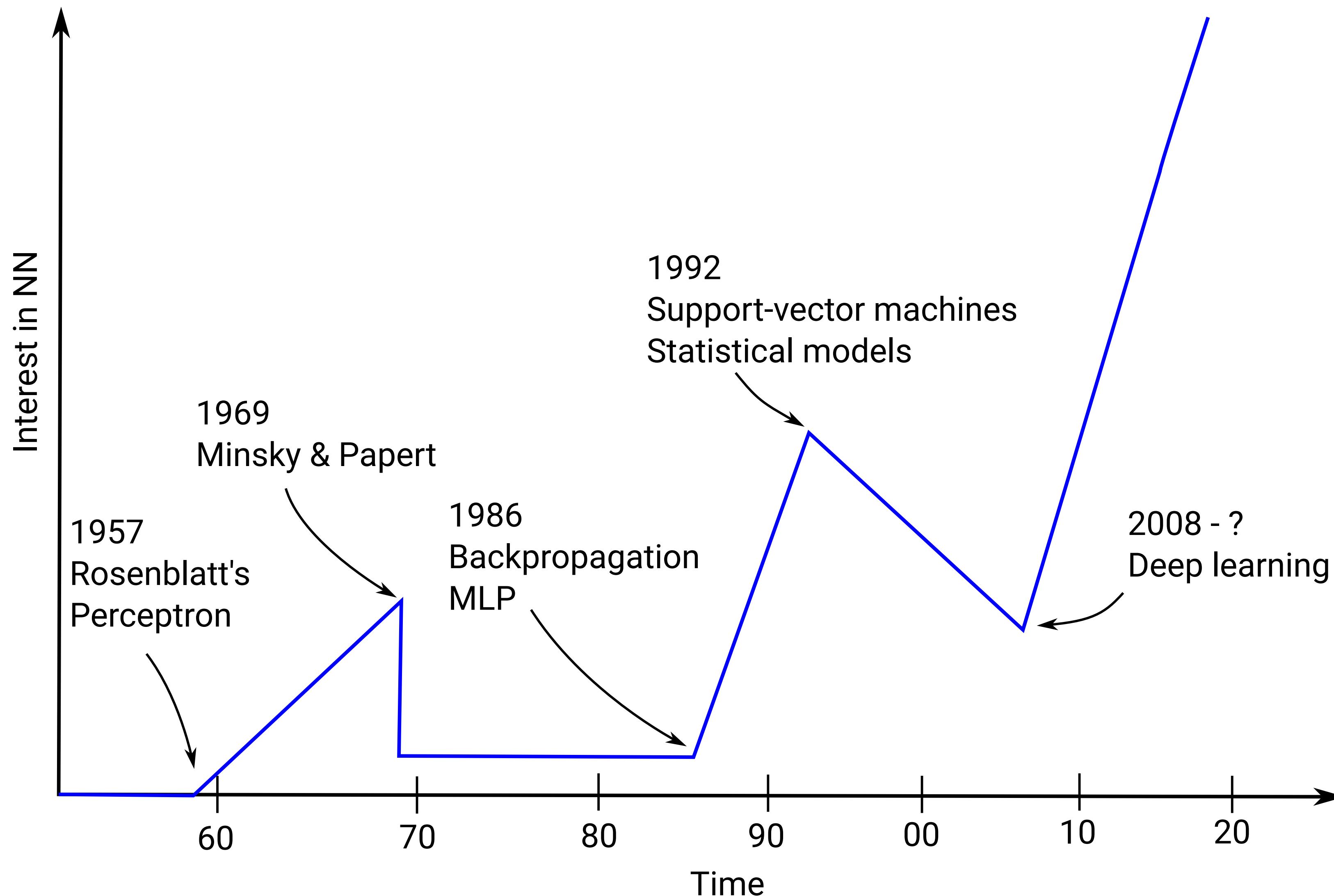
Source: <https://data-science-blog.com/blog/2018/05/14/machine-learning-vs-deep-learning-wie-liegt-der-unterschied>

Artificial Intelligence, Machine Learning, Deep Learning, Neurocomputing



- **Neurocomputing** is at the intersection between computational neuroscience and artificial neural networks (deep learning).
- Computational neuroscience studies the functioning of the brain through detailed models.
- Neurocomputing aims at bringing the mechanisms underlying human cognition into artificial intelligence.

AI hypes and AI winters

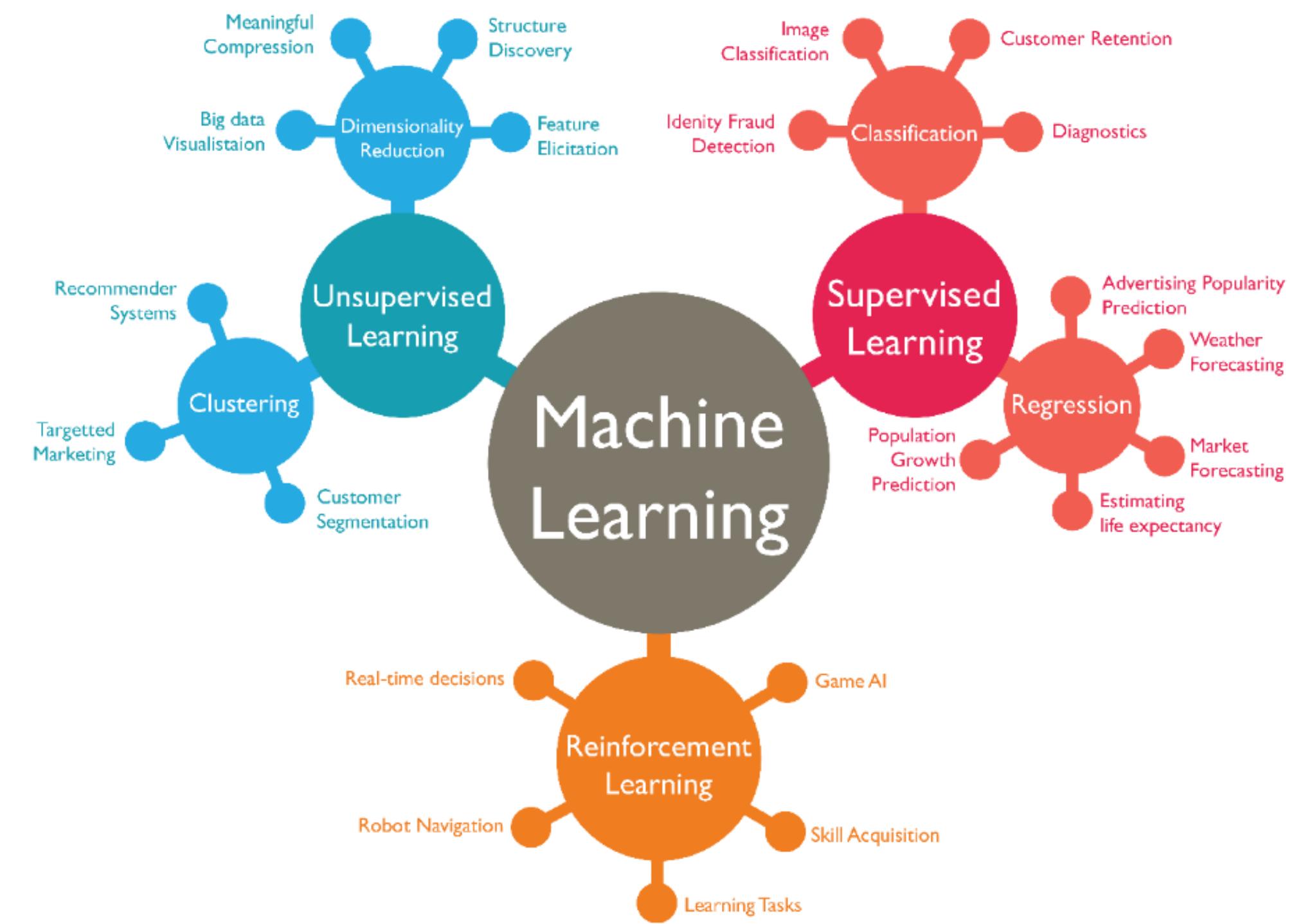


Classification of ML techniques

- **Supervised learning:** The program is trained on a pre-defined set of training examples and used to make correct predictions when given new data.
- **Unsupervised learning:** The program is given a bunch of data and must find patterns and relationships therein.
- **Reinforcement learning:** The program explores its environment by producing actions and receiving rewards.

But also:

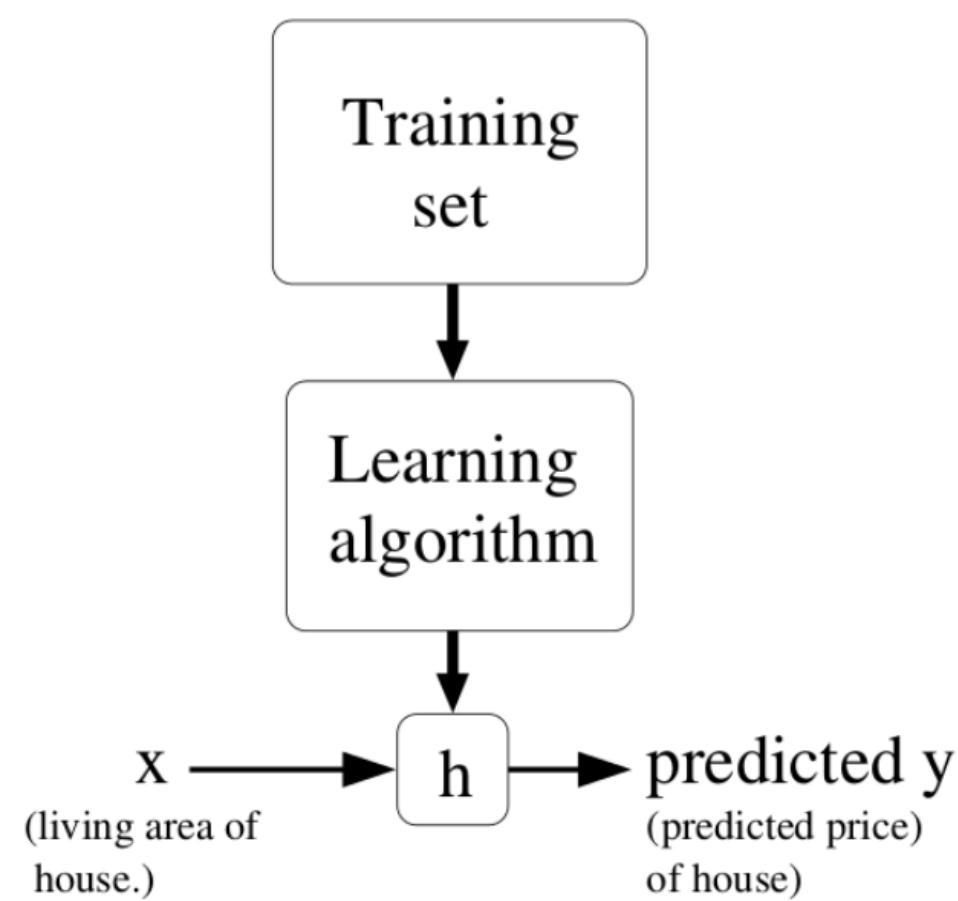
- Self-supervised learning, self-taught learning, developmental learning...



Source: <http://www.isaziconsulting.co.za/machinelearning.html>

1- Supervised learning

Supervised Learning



- **Supervised learning** consists in presenting a dataset of **input** and **output samples** (or examples) $(x_i, t_i)_{i=1}^N$ to a parameterized model.

$$y_i = f_\theta(x_i)$$

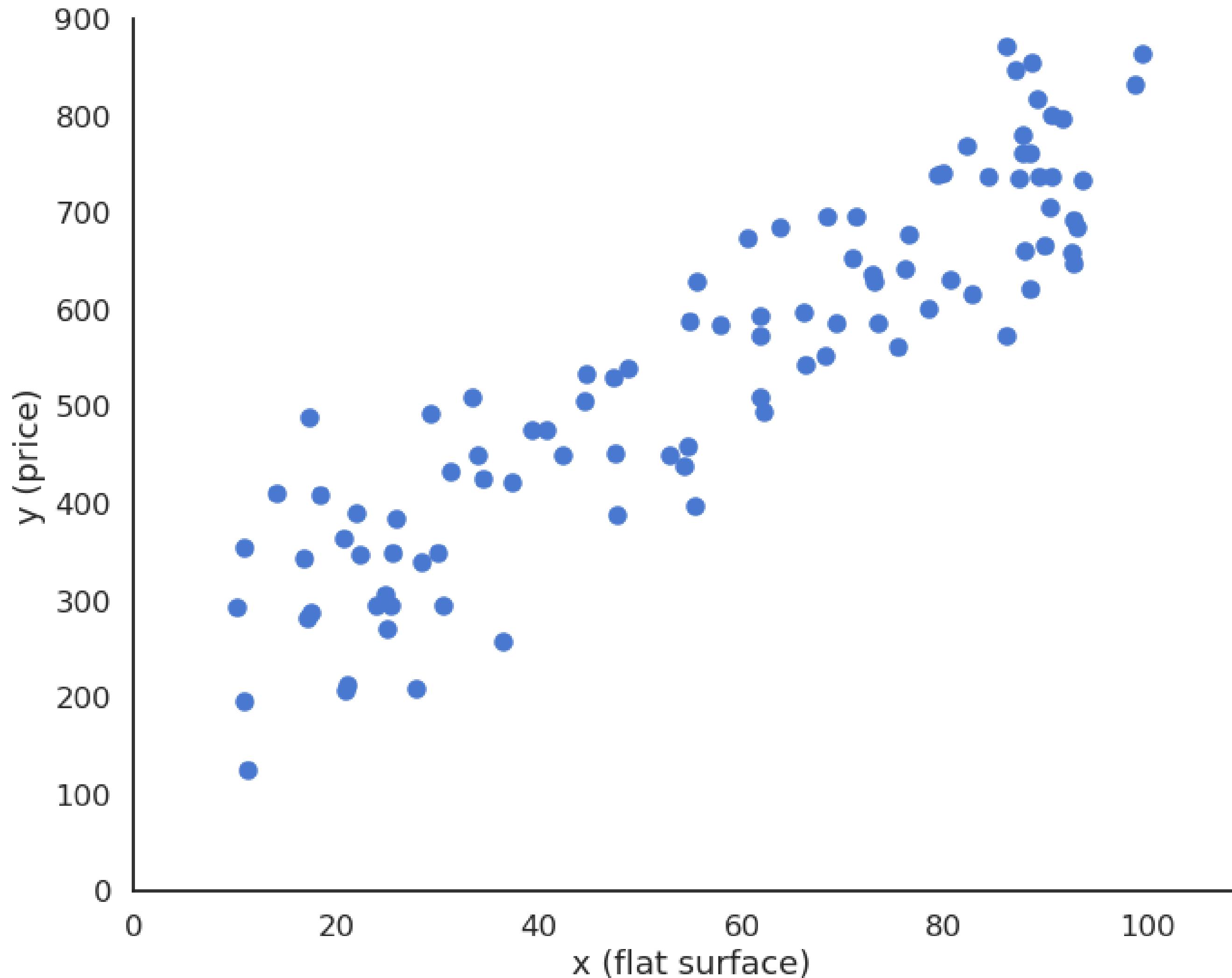
- The goal of learning is to adapt the parameters θ , so that the model reduces its **prediction error** on the training data.

$$\theta^* = \operatorname{argmin} \sum_{i=1}^N ||t_i - y_i||$$

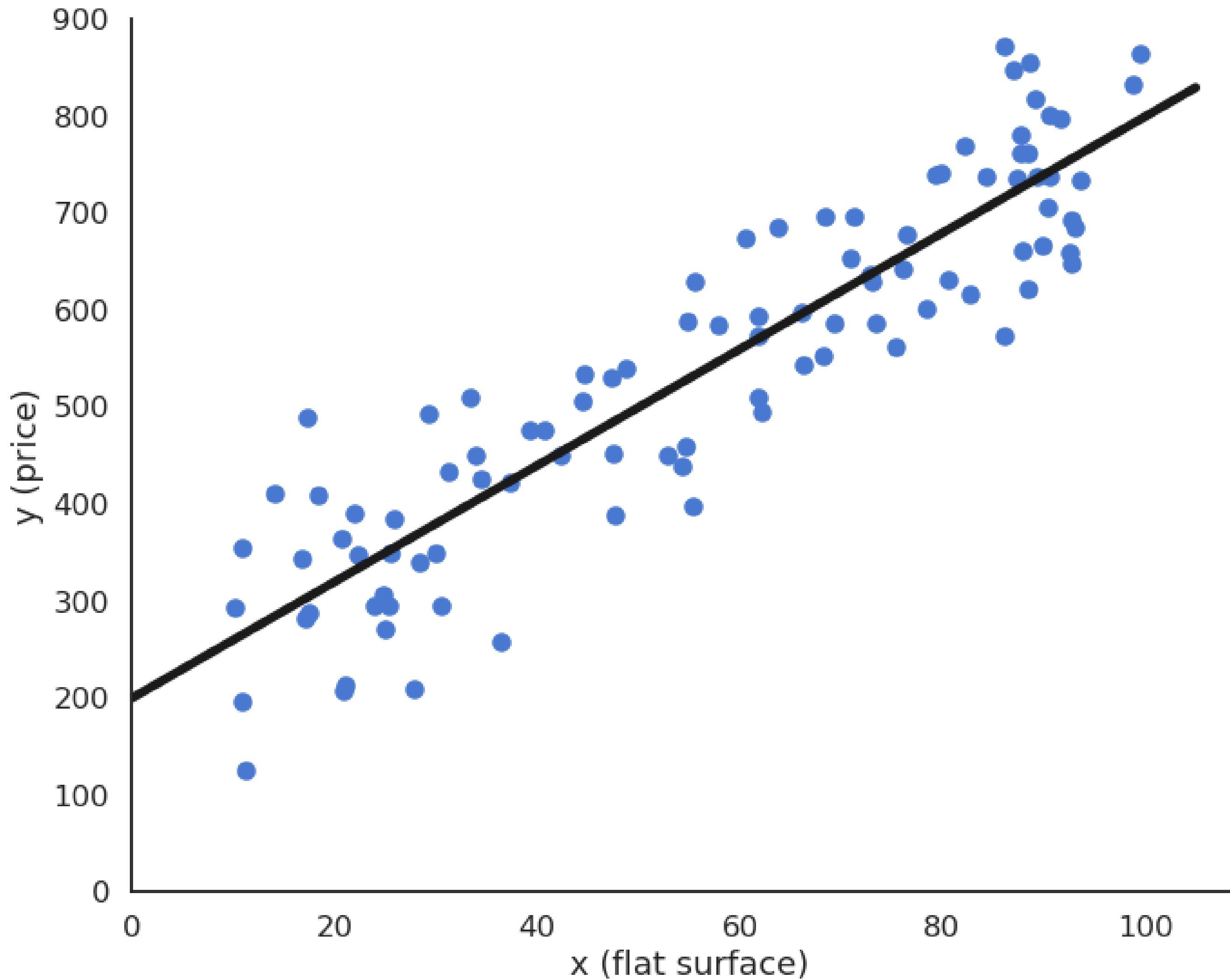
Source: Andrew Ng, Stanford CS229,
<https://see.stanford.edu/materials/aimlcs229/cs229-notes1.pdf>

- When learning is successful, the model can be used on novel examples (**generalisation**).
- The modality of the inputs and outputs does not really matter:
 - Image → Label : **image classification**
 - Image → Image : **semantic segmentation**
 - Speech → Text : **speech recognition**
 - Text → Speech : **speech synthesis**

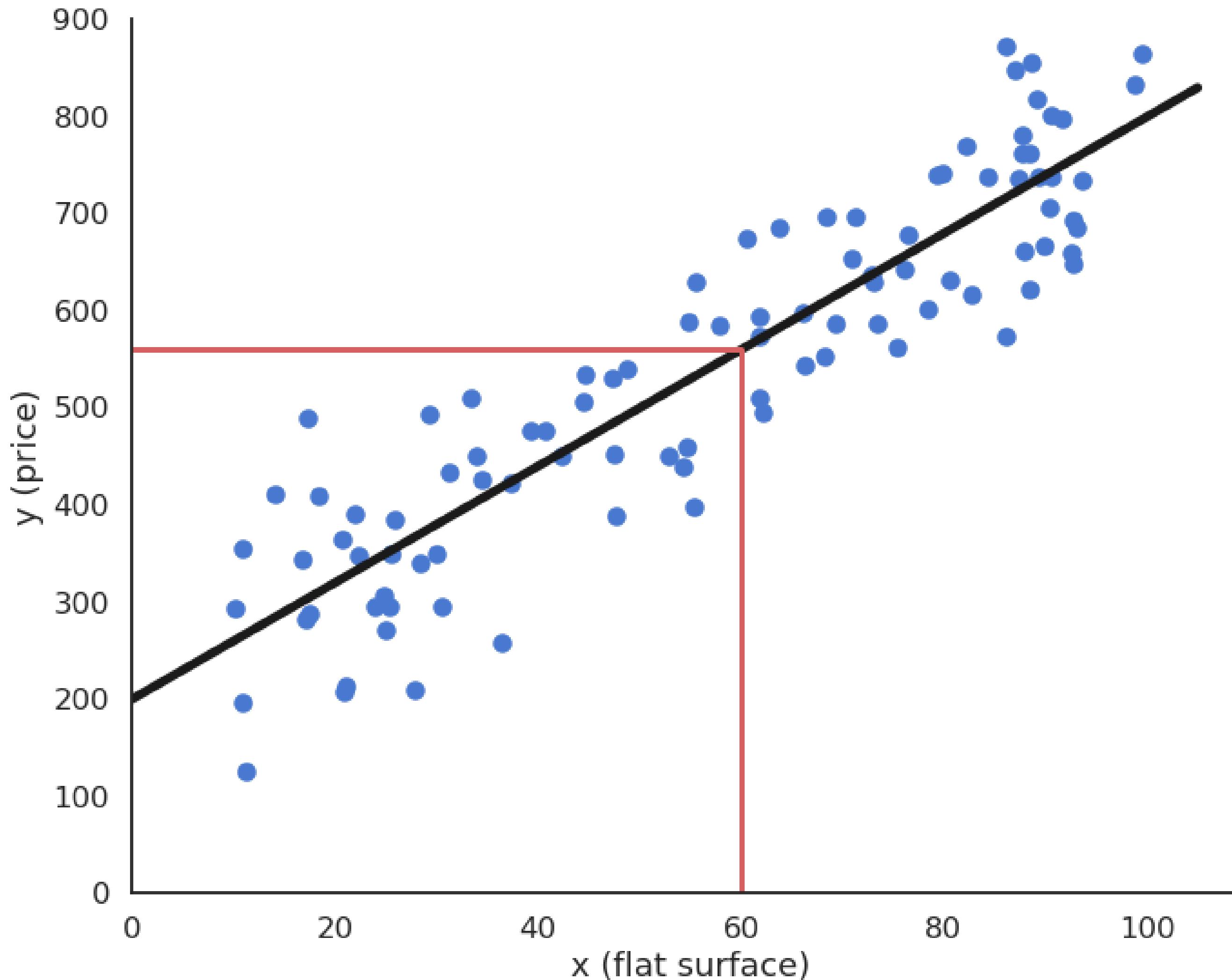
Supervised learning : regression



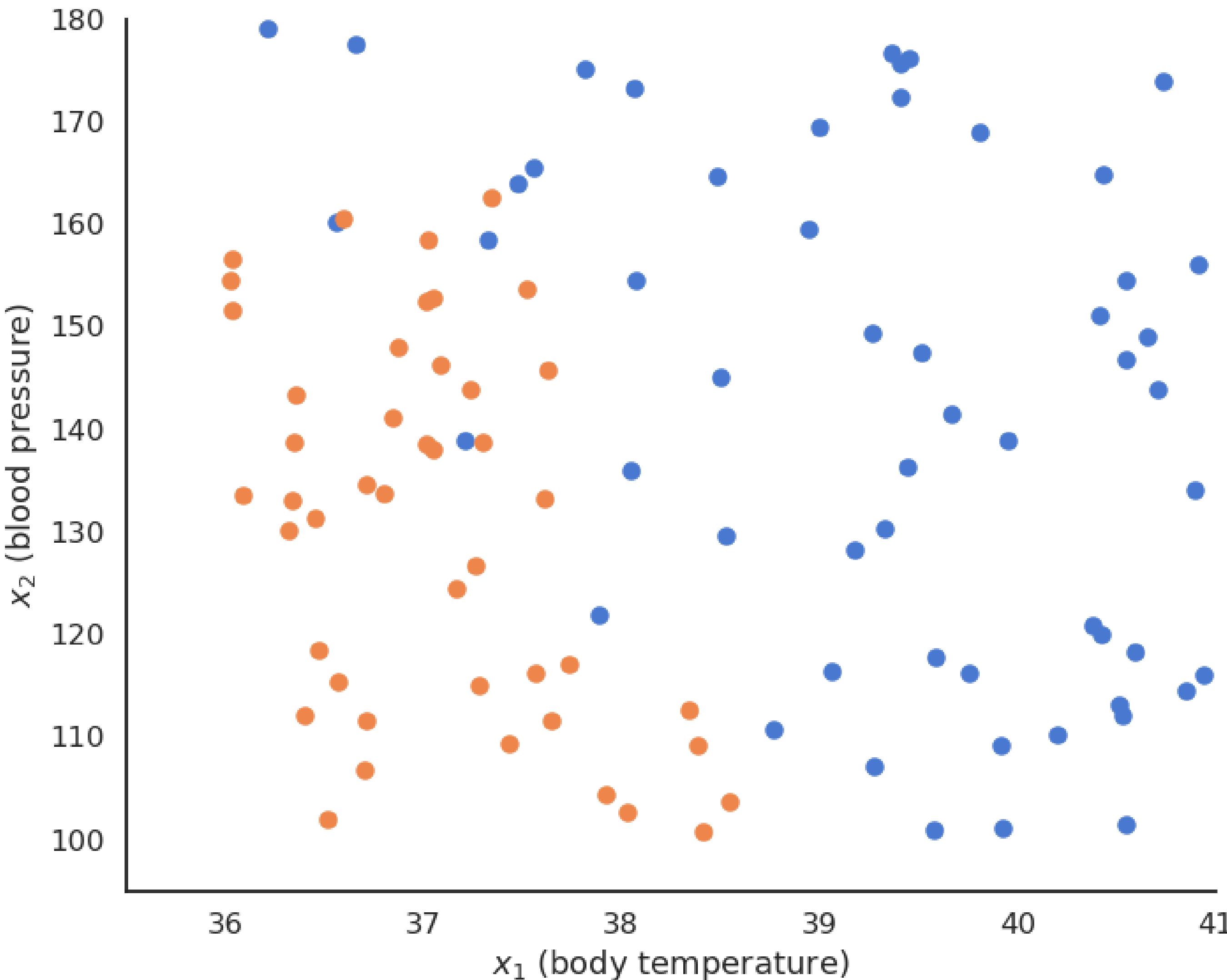
Supervised learning : regression



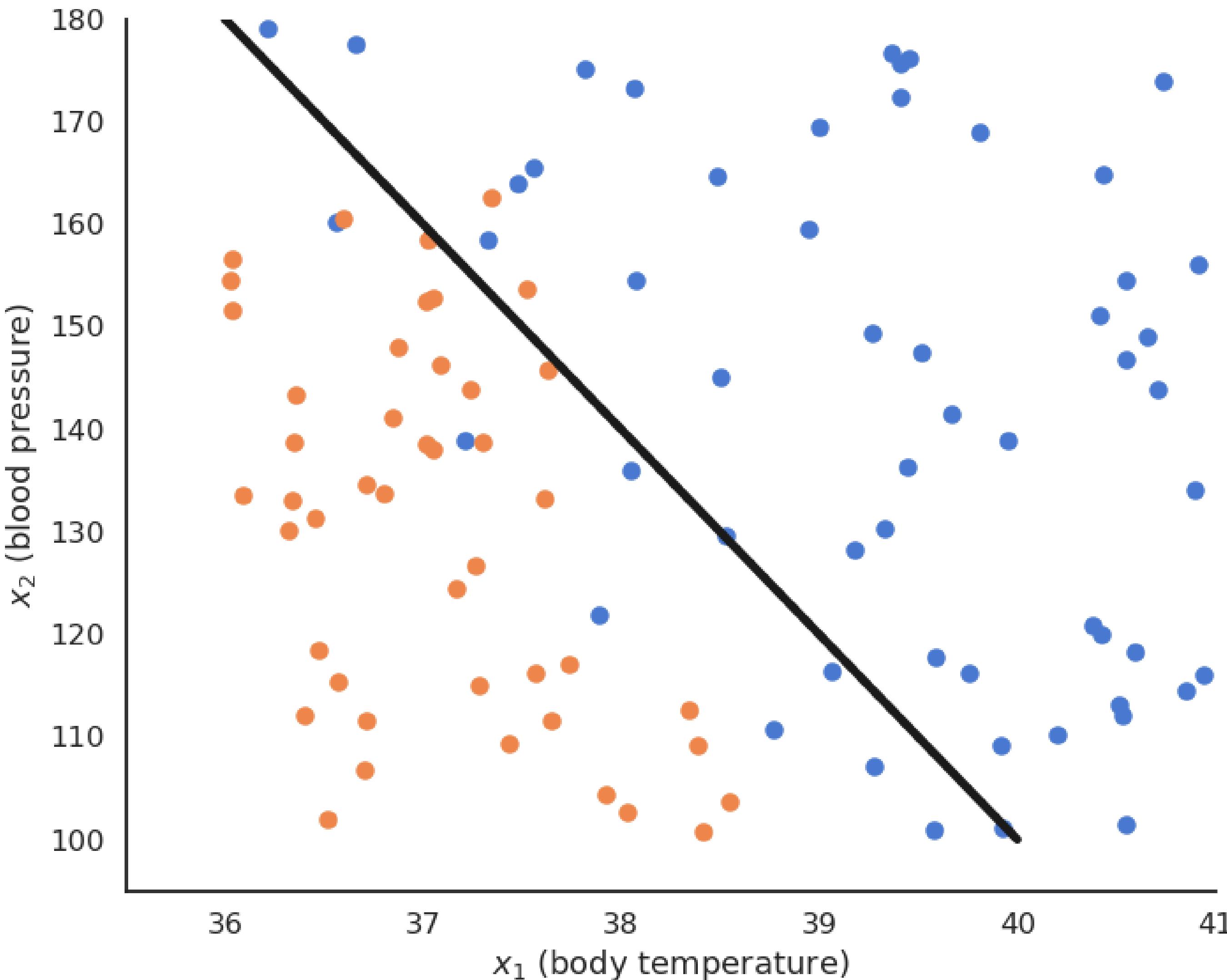
Supervised learning : regression



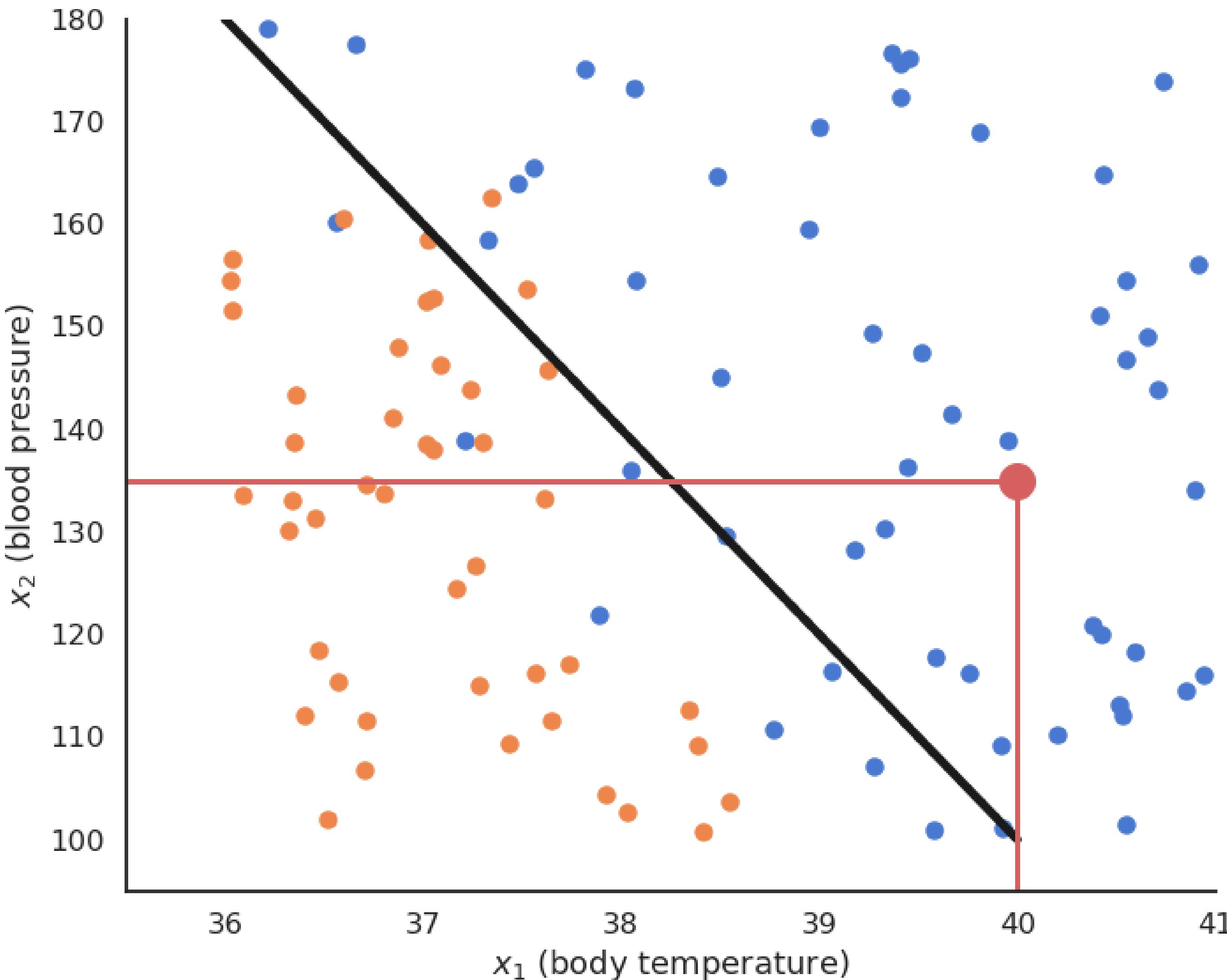
Supervised learning : classification



Supervised learning : classification

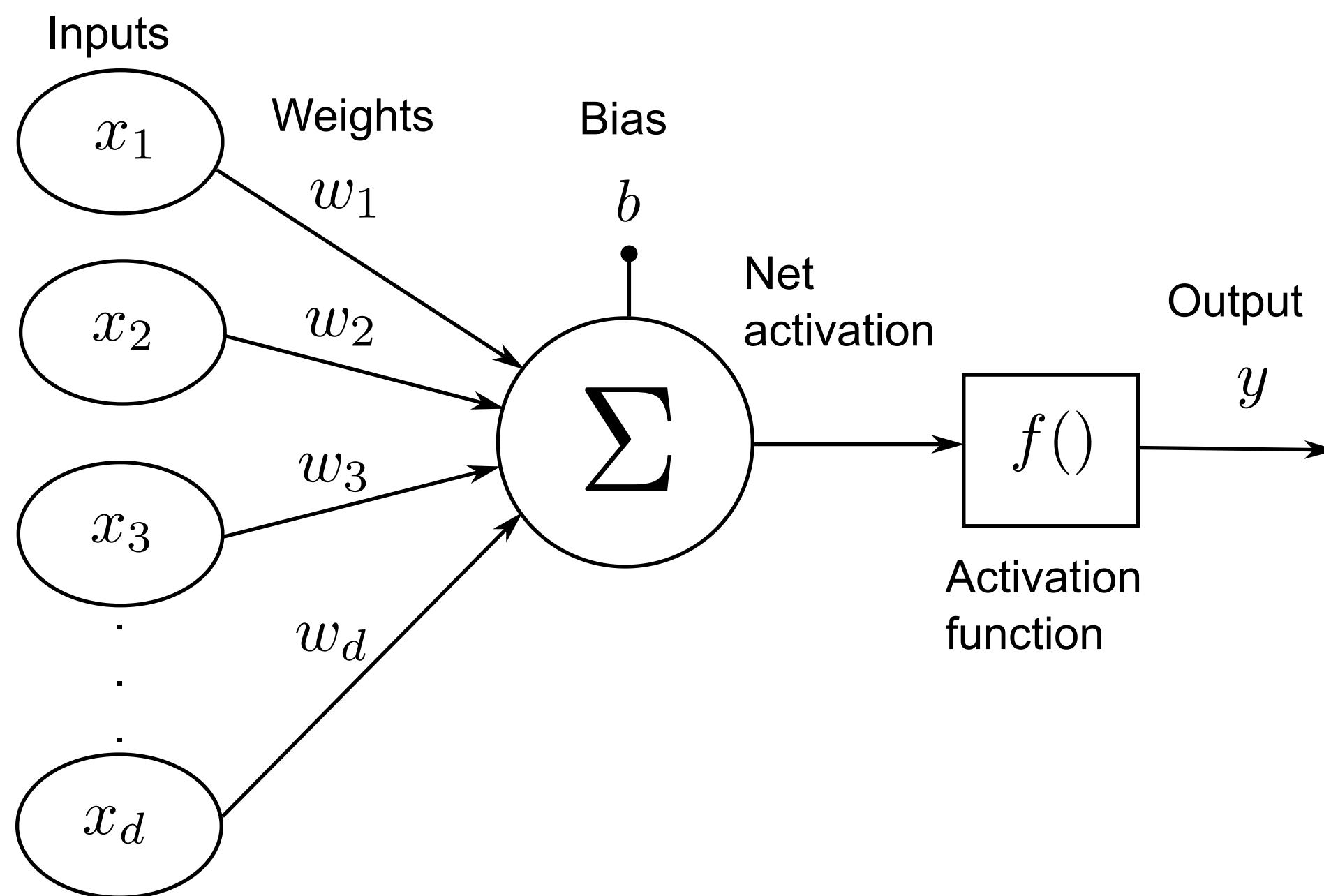


Supervised learning : classification



The artificial neuron

- A single artificial neuron is able to solve linear classification/regression problems:

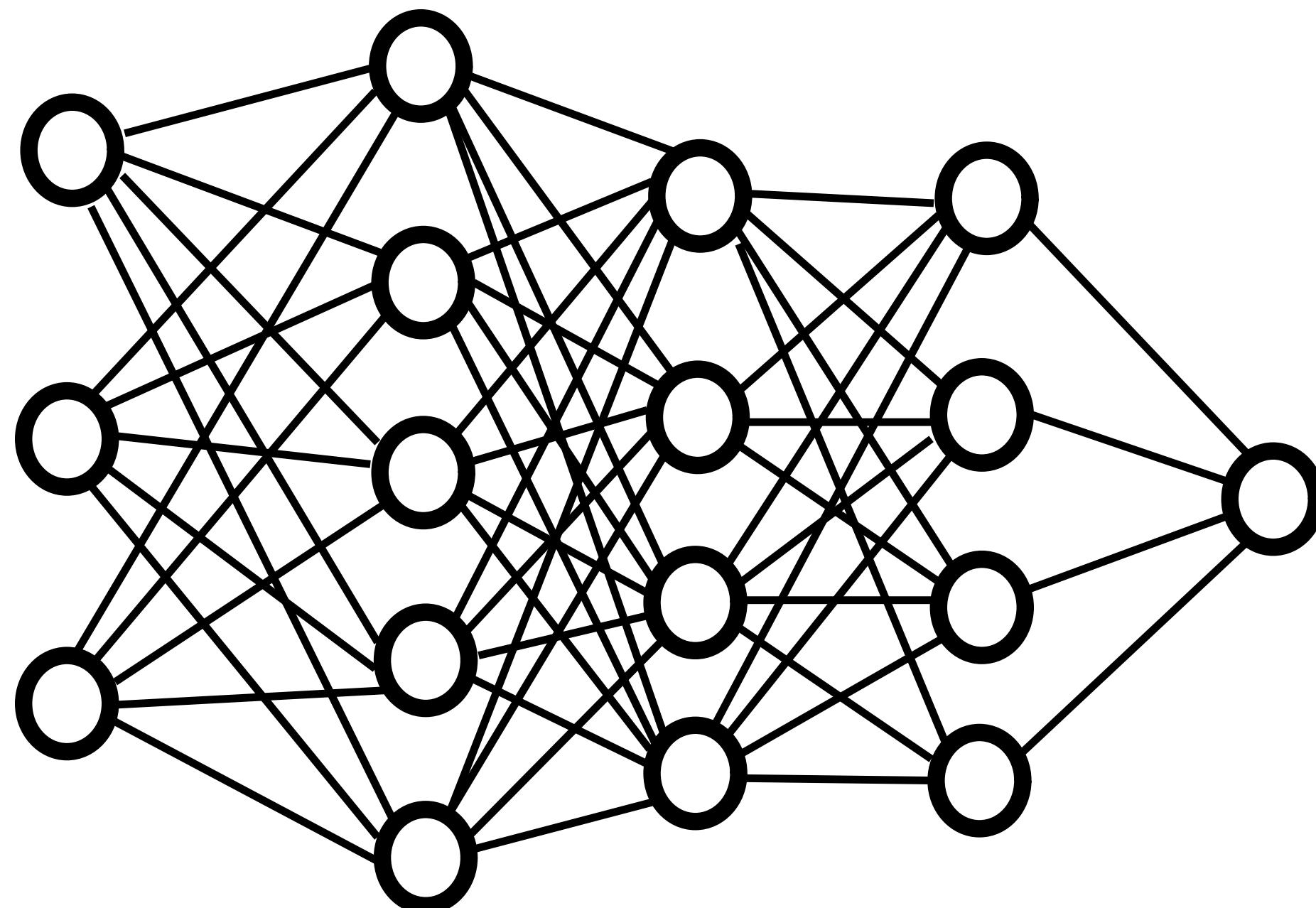


$$y = f\left(\sum_{i=1}^d w_i x_i + b\right)$$

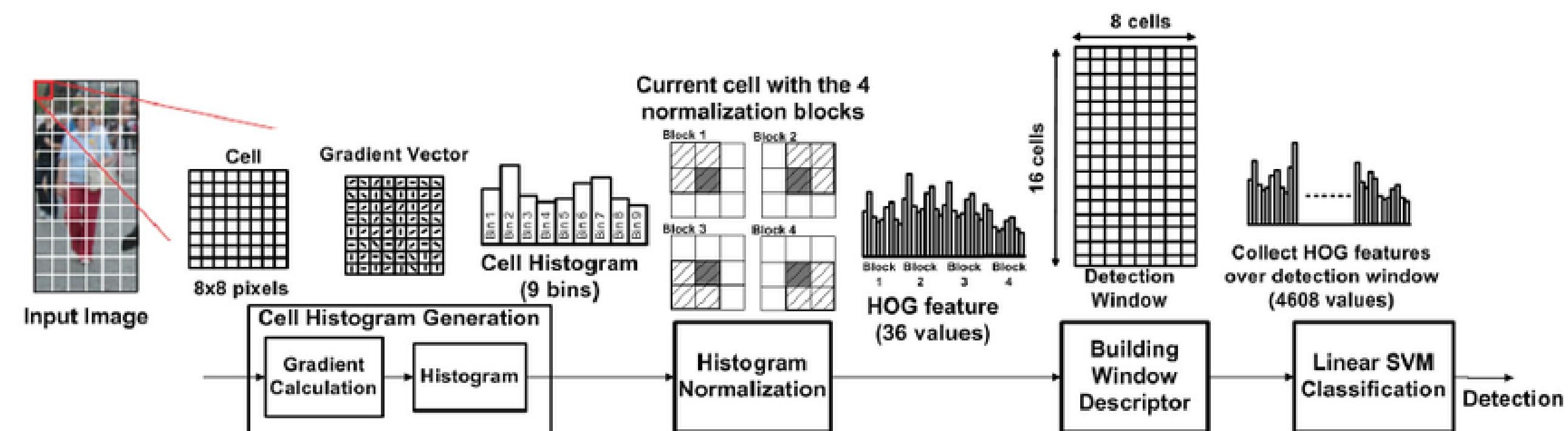
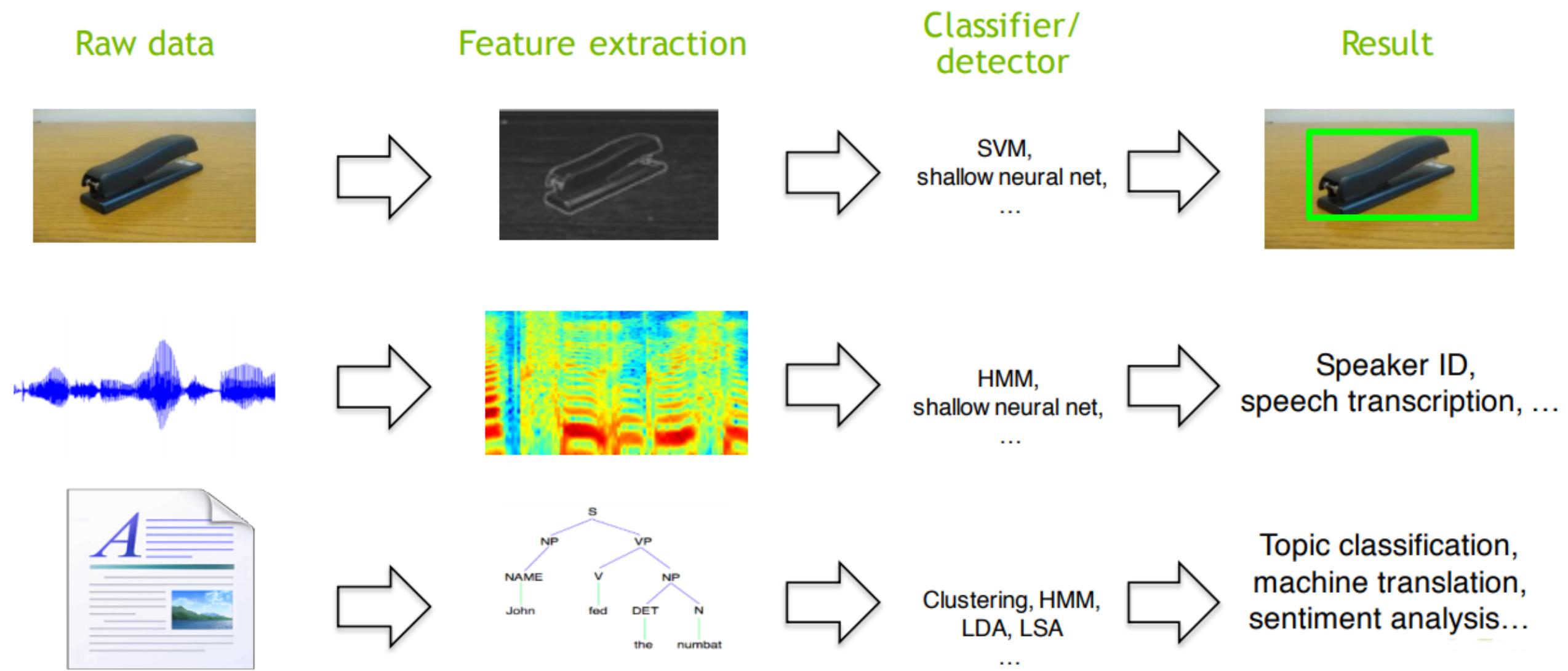
- A neuron integrates inputs x_i by multiplying them with weights w_i , adds a bias b and transforms the result into an output y using a transfer function (or activation function) f .

Artificial Neural Network

- A **neural network** (NN) is able to solve non-linear classification/regression problems by combining many artificial neurons.



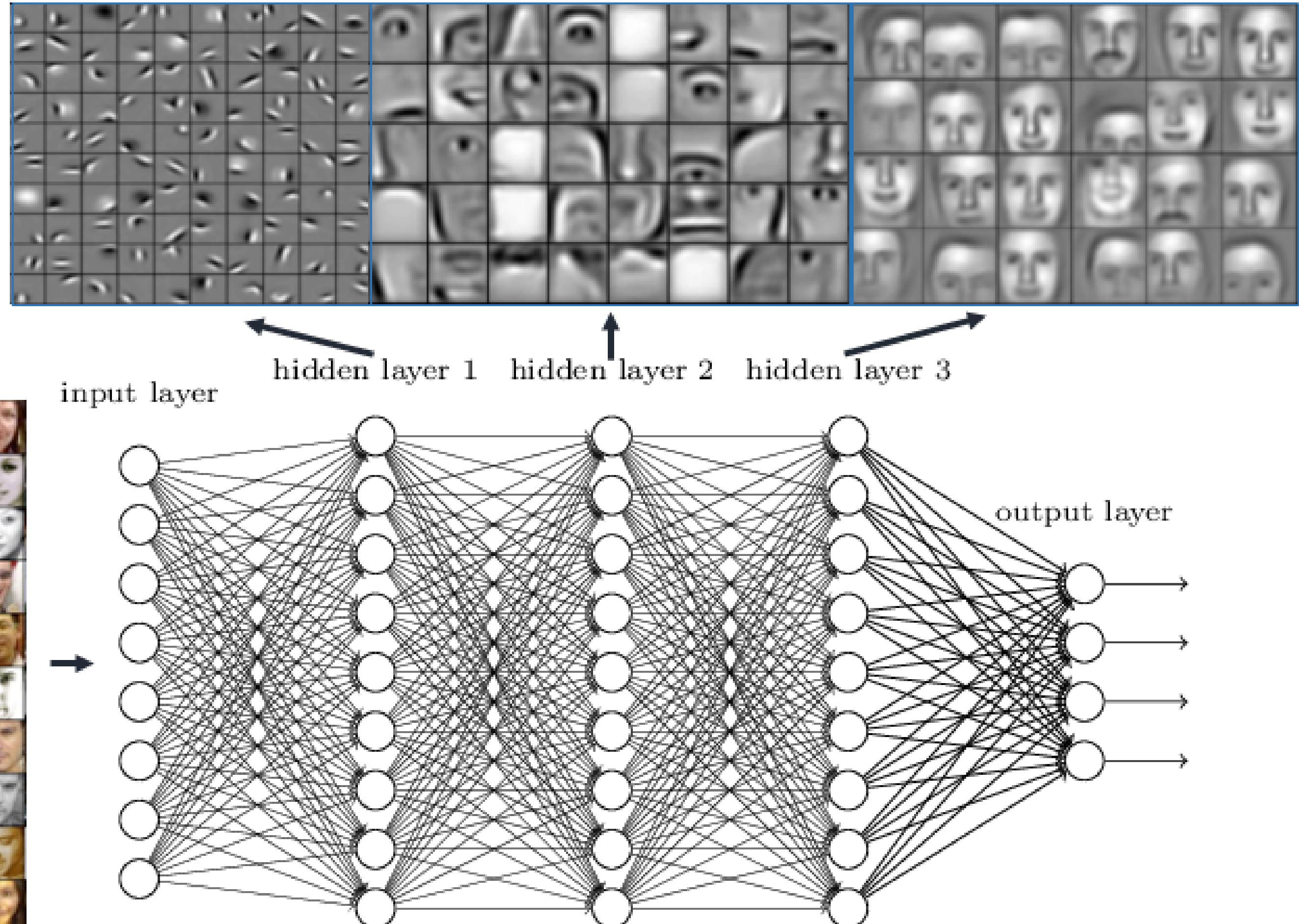
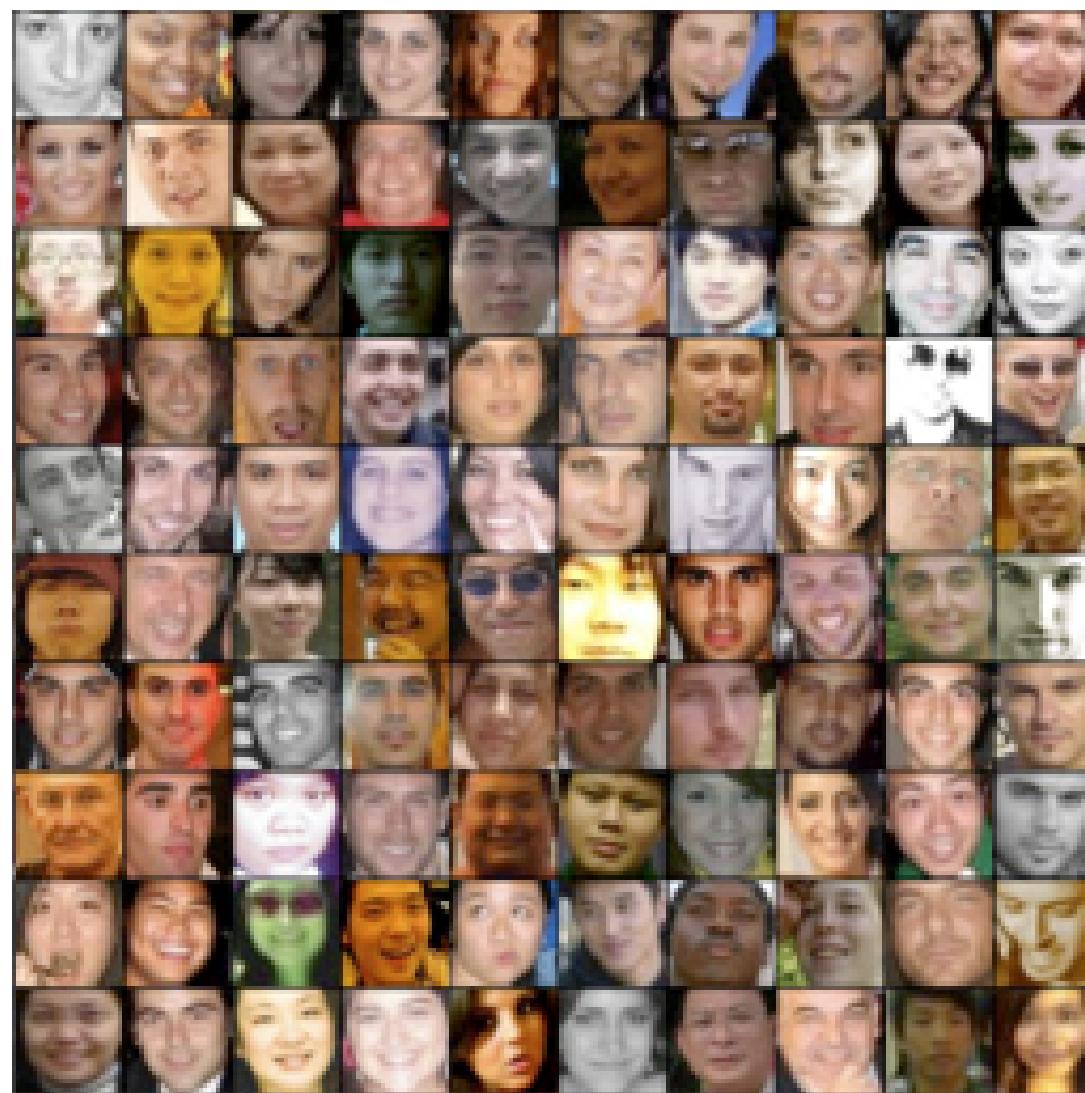
Classical approach to pattern recognition



Deep Learning approach to pattern recognition

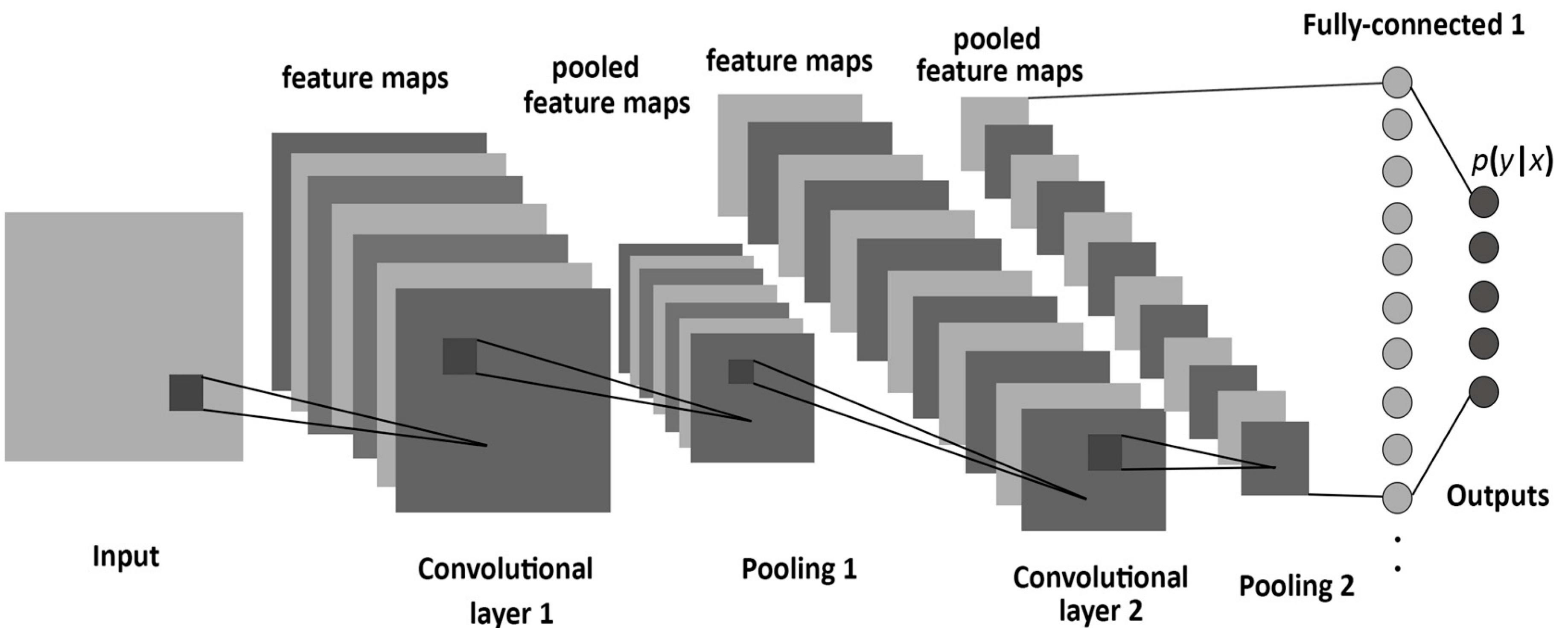
- **End-to-end** learning: the NN is trained directly on the raw data (pixels, sounds, text) and solves a non-linear classification/regression problem.

Deep neural networks learn hierarchical feature representations



Convolutional neural networks

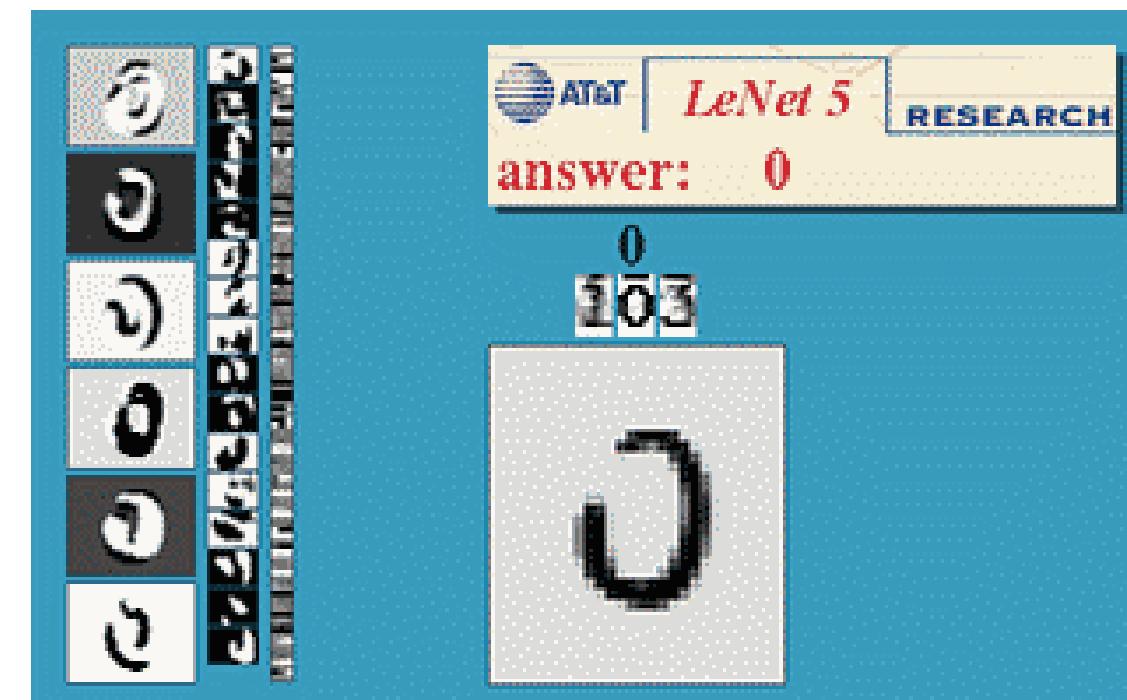
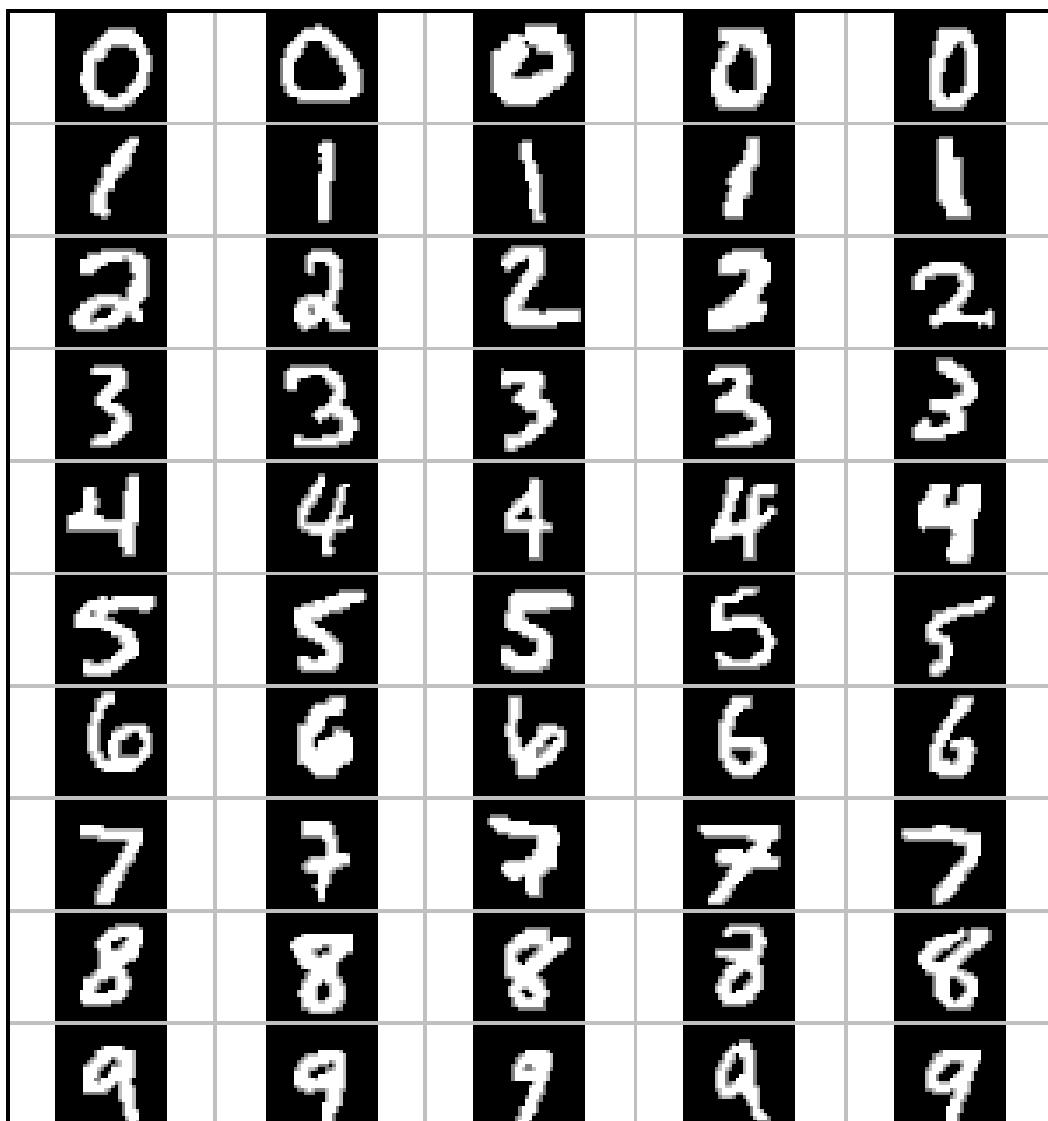
- A **convolutional neural network** (CNN) is a cascade of convolution and pooling operations, extracting layer by layer increasingly complex features.
- It can be trained on huge datasets of annotated examples.



Albelwi S, Mahmood A. 2017. A Framework for Designing the Architectures of Deep Convolutional Neural Networks. Entropy 19:242.
doi:10.3390/e19060242

Handwriting recognition

- The MNIST database is the simplest benchmark for object recognition (> 99.5 %).
- One of the early functional CNN was LeNet5, able to classify digits.



LeCun et al. (1998). Gradient-Based Learning Applied to Document Recognition (Proc. IEEE 1998)

ImageNet recognition challenge

- The ImageNet challenge was a benchmark for computer vision algorithms, providing millions of annotated images for object recognition, detection and segmentation.

Object recognition

Easiest classes

red fox (100) hen-of-the-woods (100) ibex (100) goldfinch (100) flat-coated retriever (100)

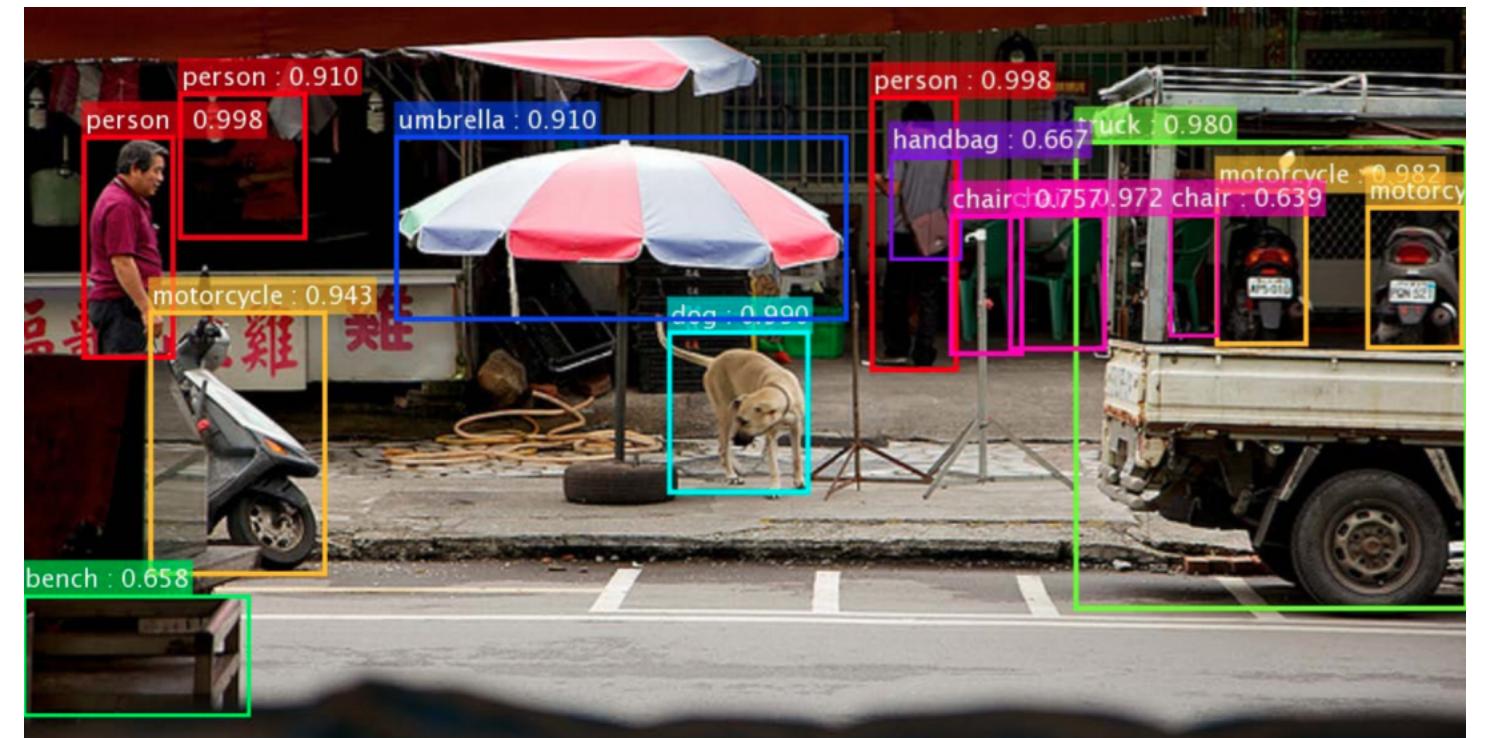


Hardest classes

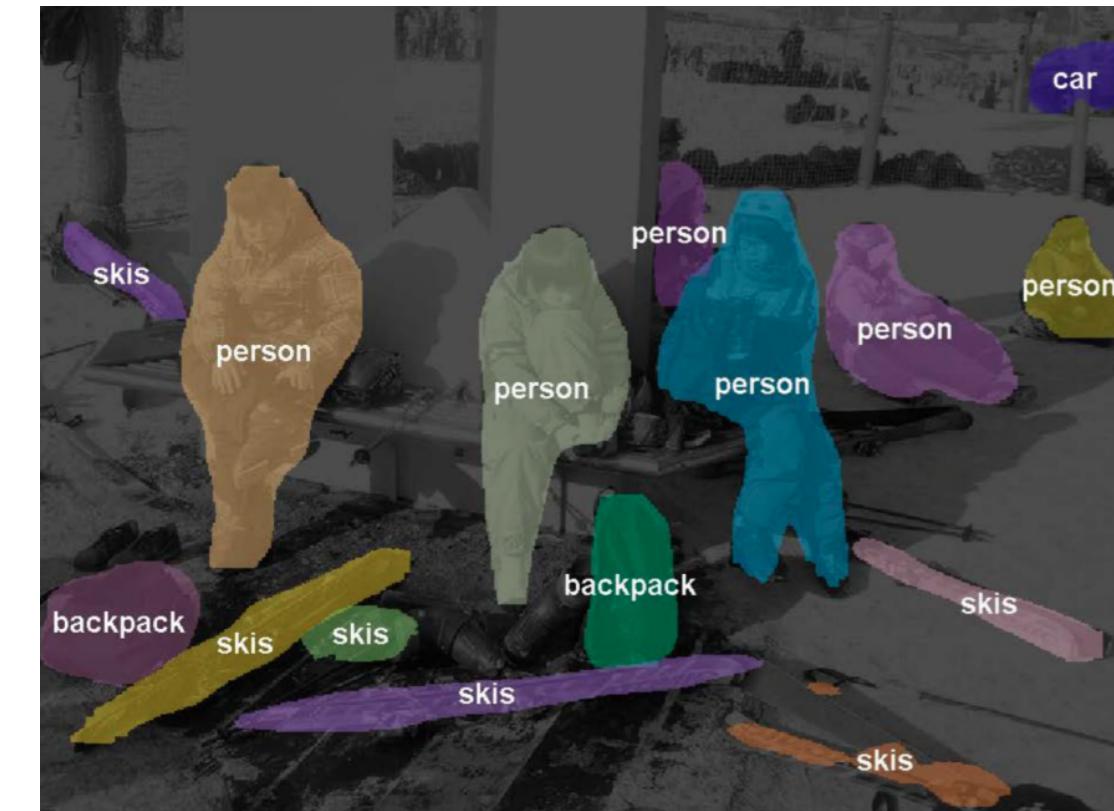
muzzle (71) hatchet (68) water bottle (68) velvet (68) loupe (66)



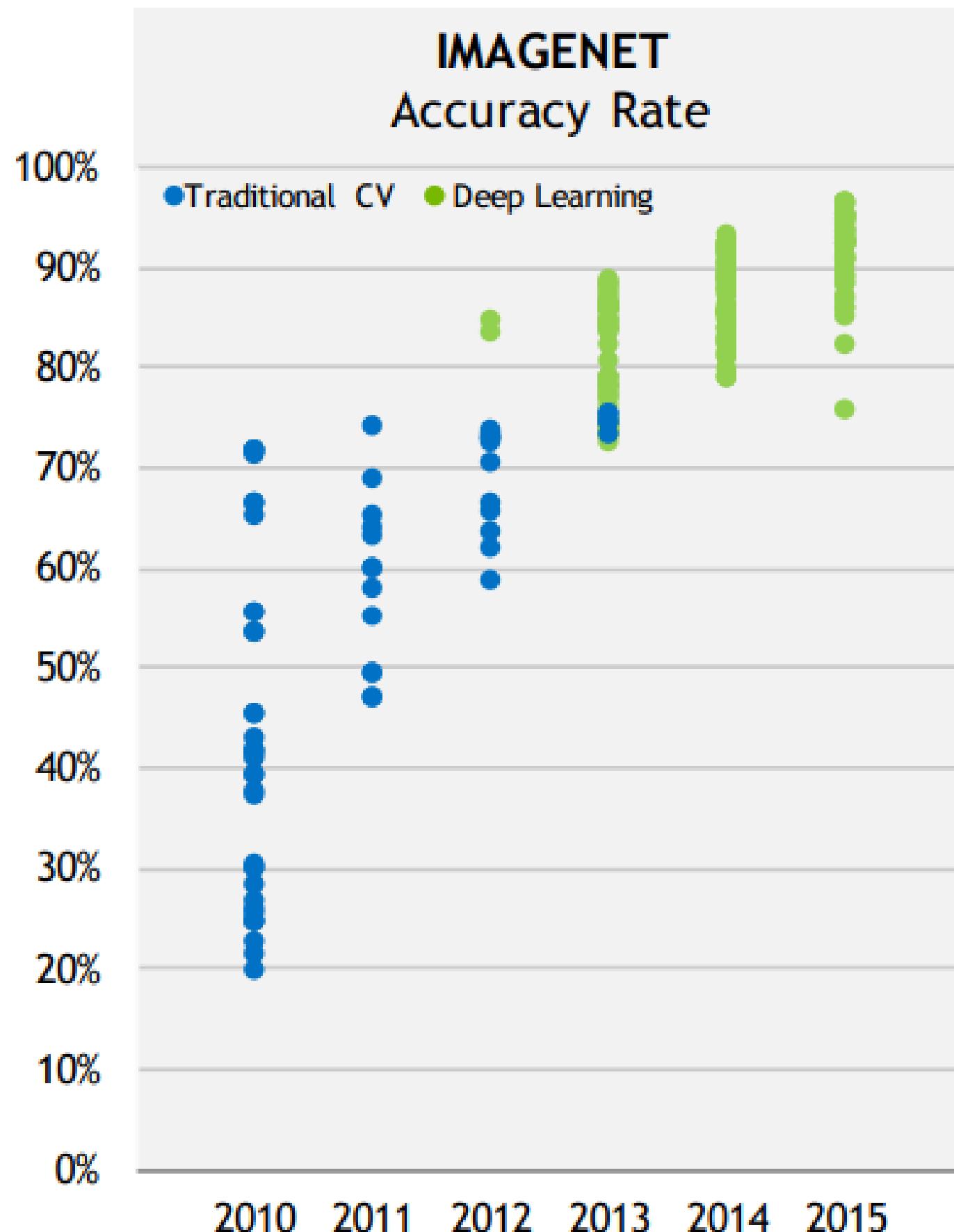
Object detection



Object segmentation



AlexNet

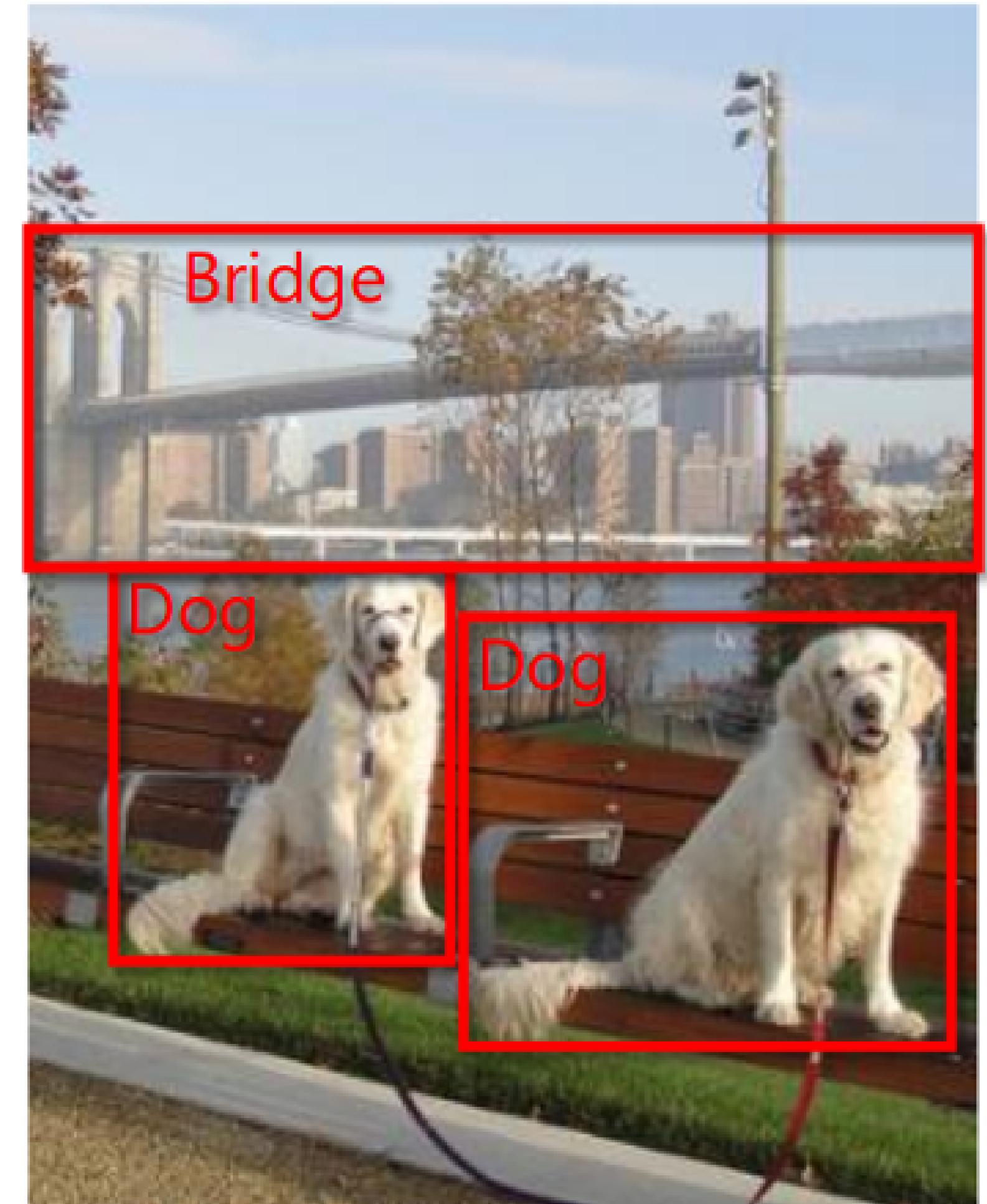


- Classical computer vision methods obtained moderate results, with error rates around 30%.
- In 2012, Alex Krizhevsky, Ilya Sutskever and Geoffrey E. Hinton (Uni Toronto) used a CNN (**AlexNet**) without any preprocessing, using directly images as inputs.
- To the big surprise of everybody, they won with an error rate of 15%, half of what other methods could achieve.
- Since then, everybody uses deep neural networks for object recognition.
- The deep learning hype had just begun...
 - Computer vision
 - Natural language processing
 - Speech processing
 - Robotics, control

Object detection



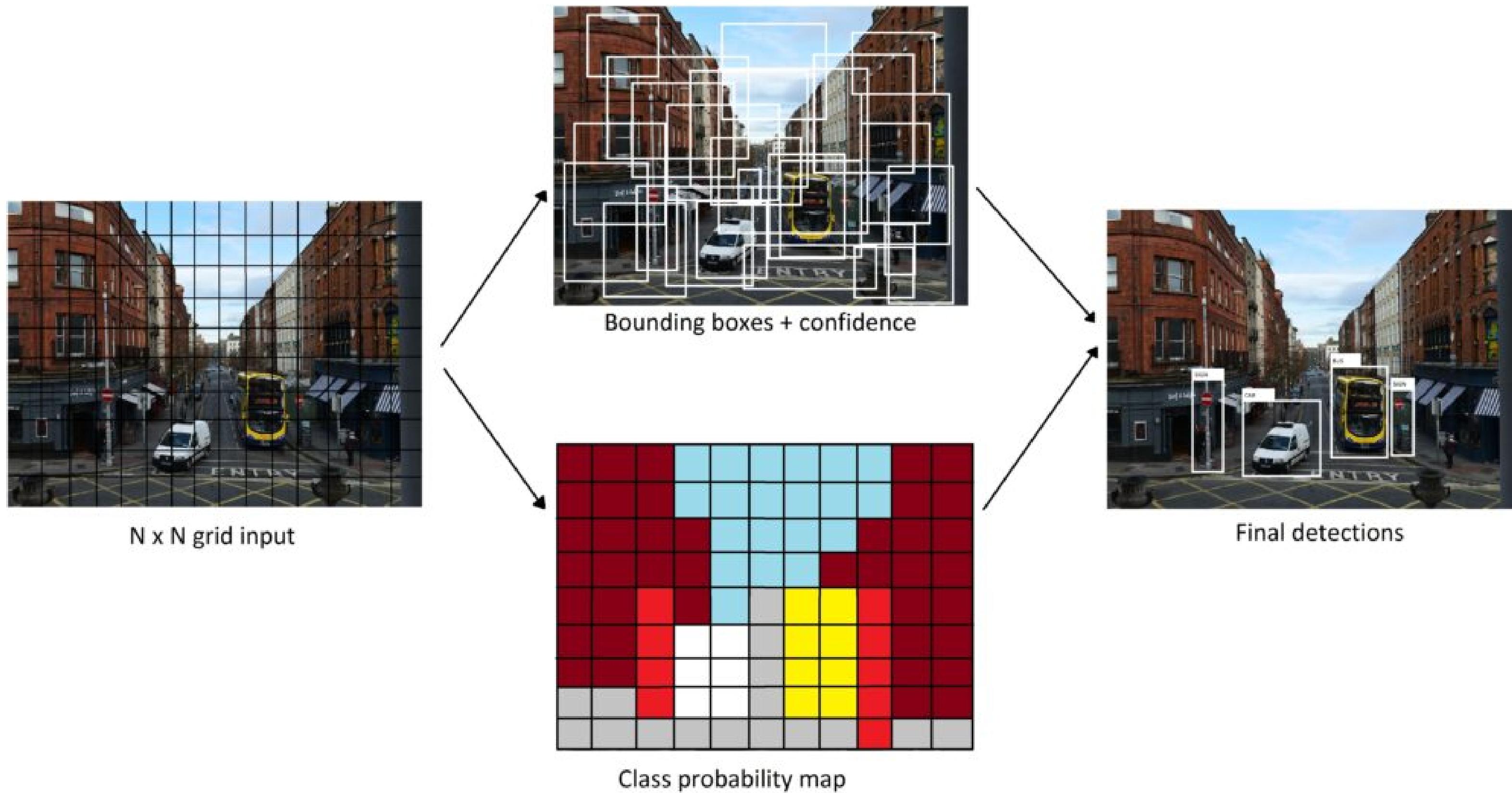
Classification, easy these days



Object detection, still a lot harder

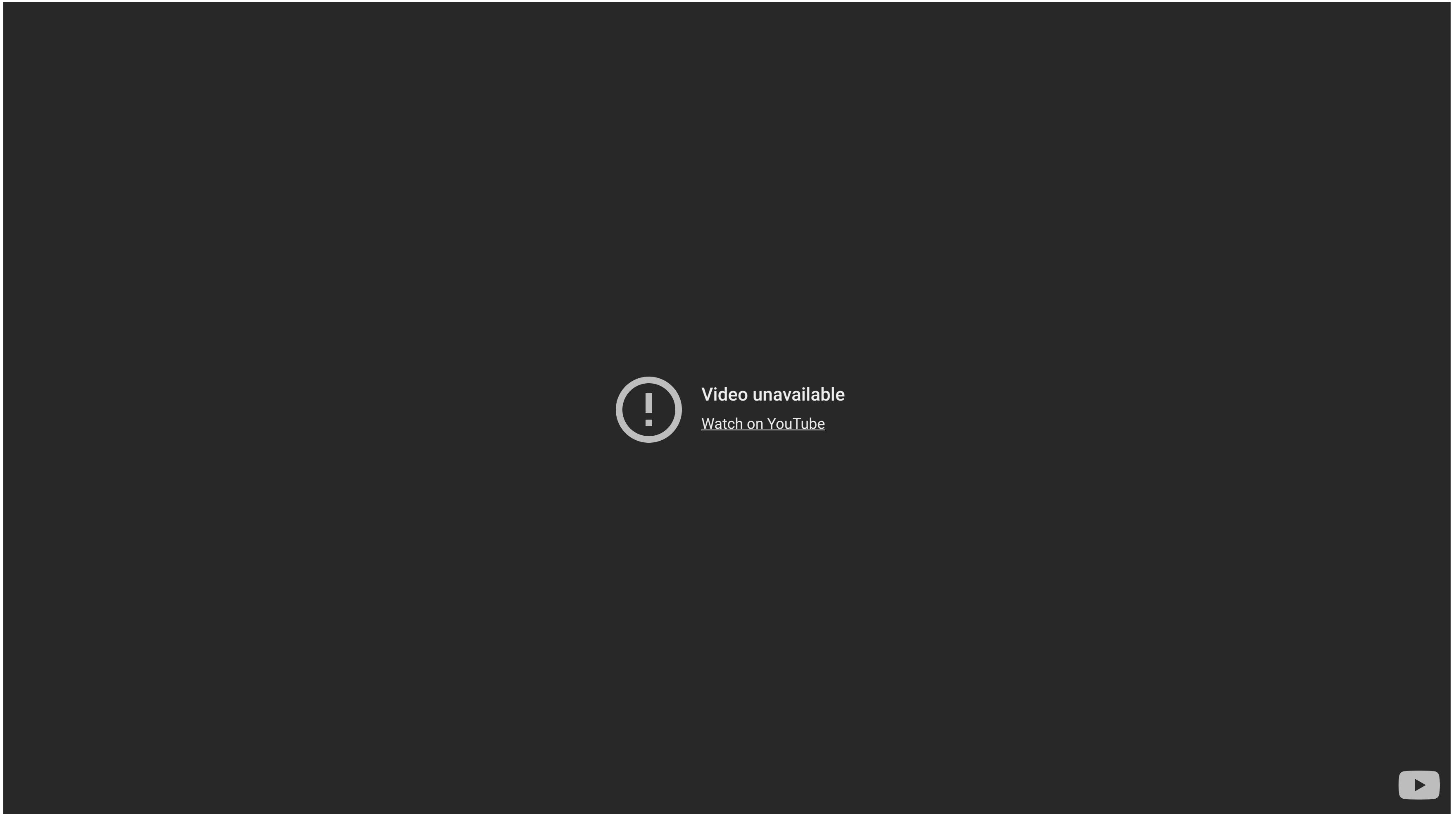
Object detection

- It turns out object detection is both a classification (what) and regression (where) problem.
- Neural networks can be trained to do it given enough annotated data.



Source: <http://datahacker.rs/od1-yolo-object-detection/>

Object detection



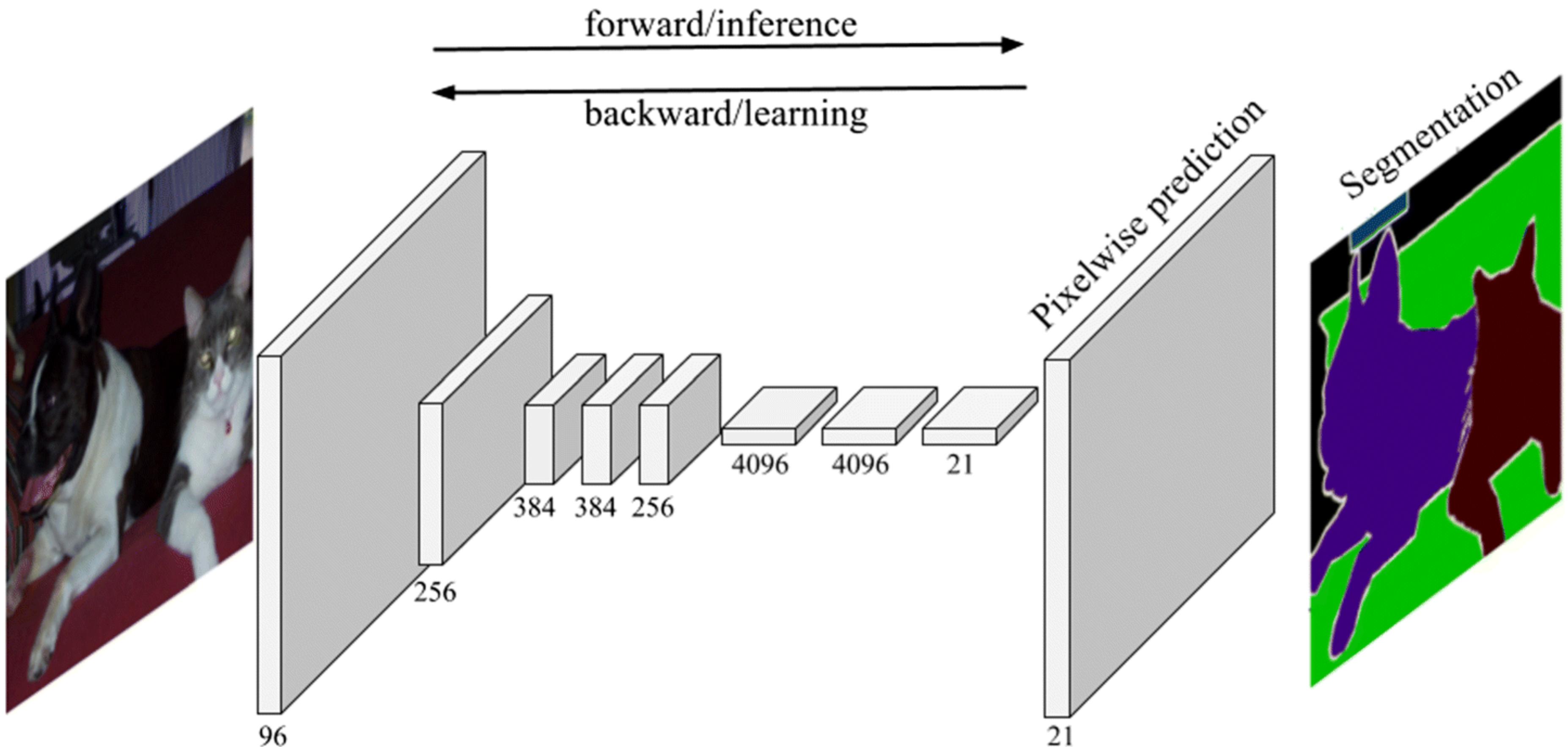
Video unavailable

[Watch on YouTube](#)



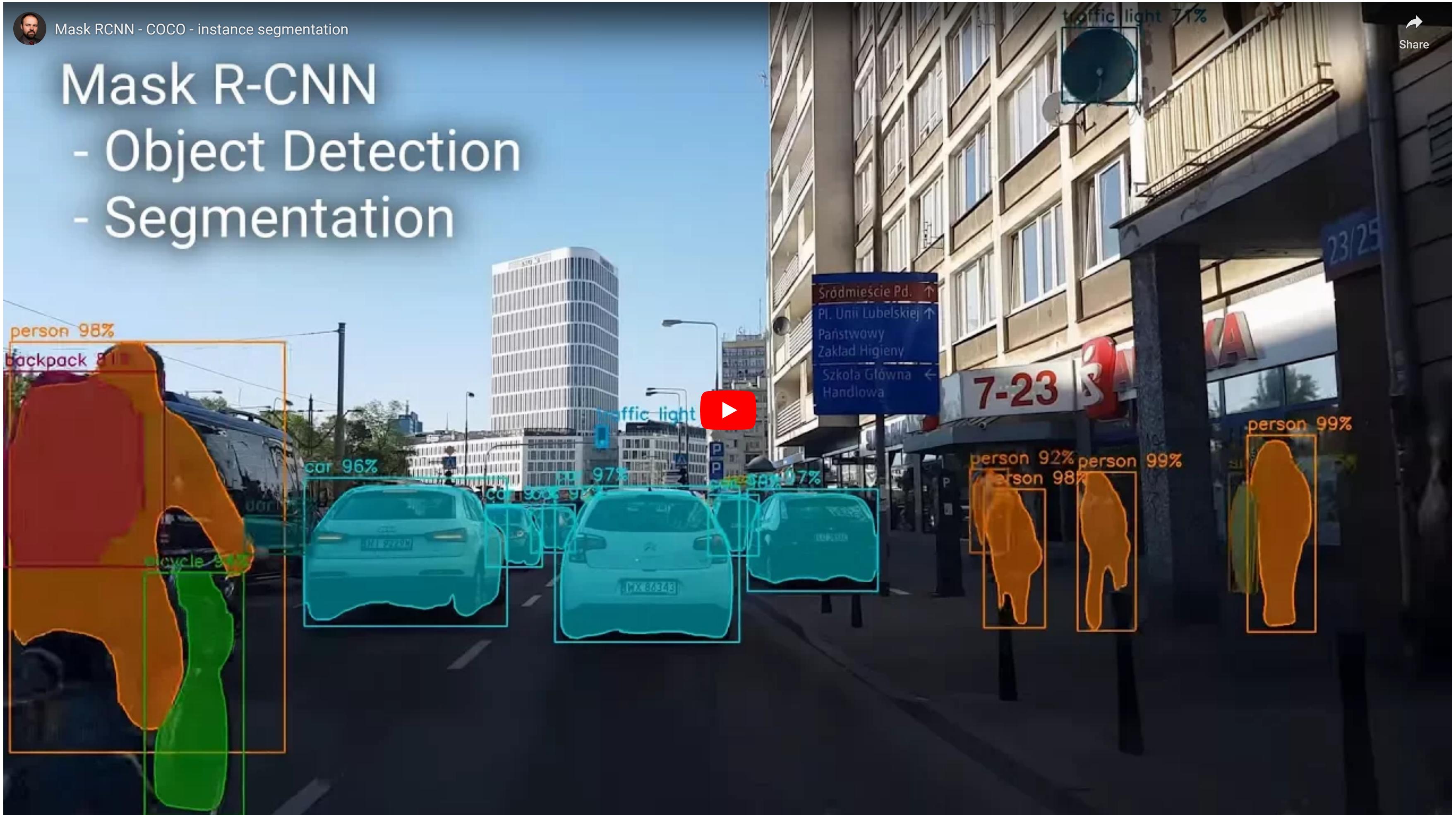
Semantic segmentation

- Classes can be predicted at the pixel level, allowing **semantic segmentation**.

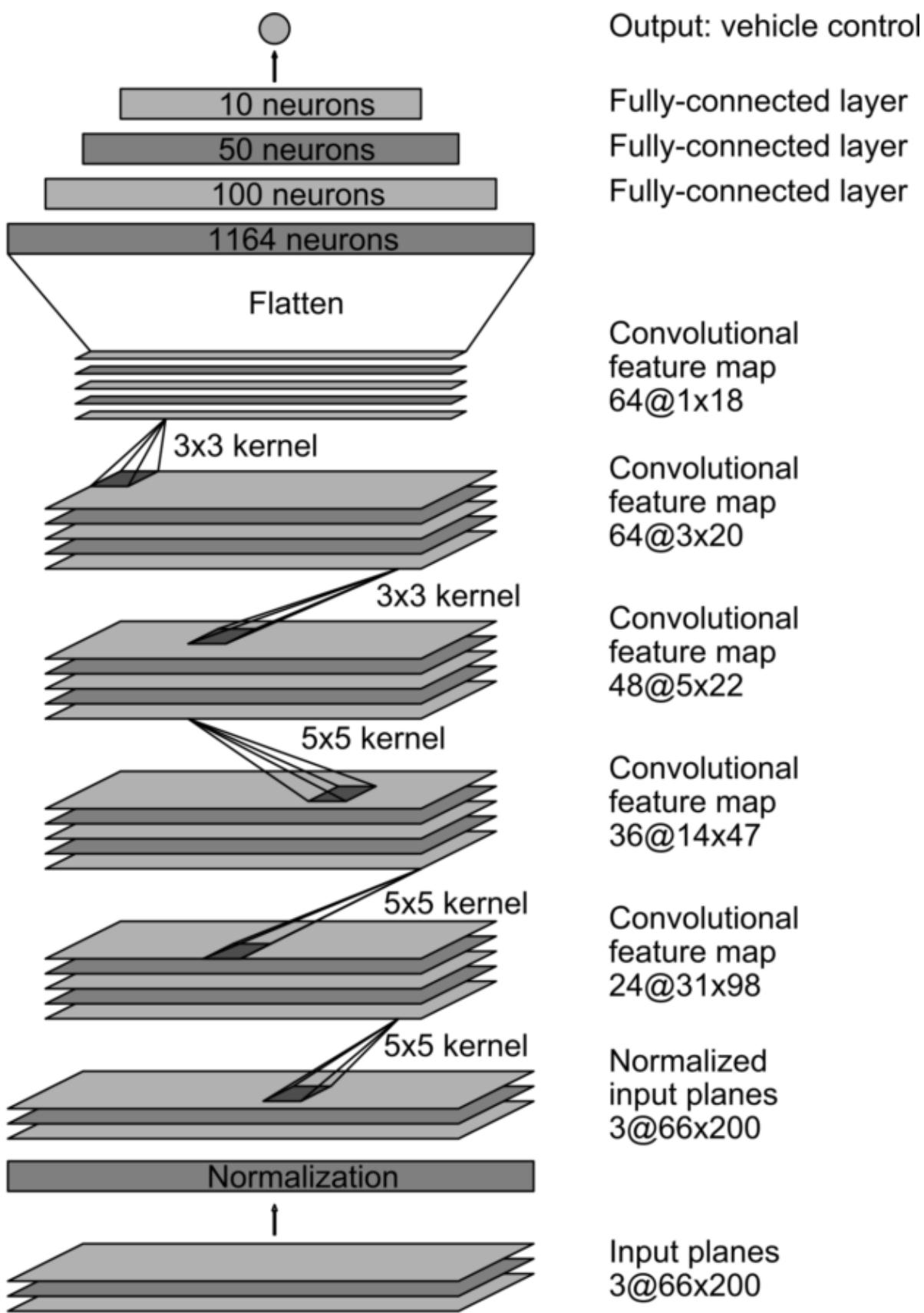


Badrinarayanan, Handa and Cipolla (2015). "SegNet: A Deep Convolutional Encoder-Decoder Architecture for Robust Semantic Pixel-Wise Labelling." arXiv:1505.07293

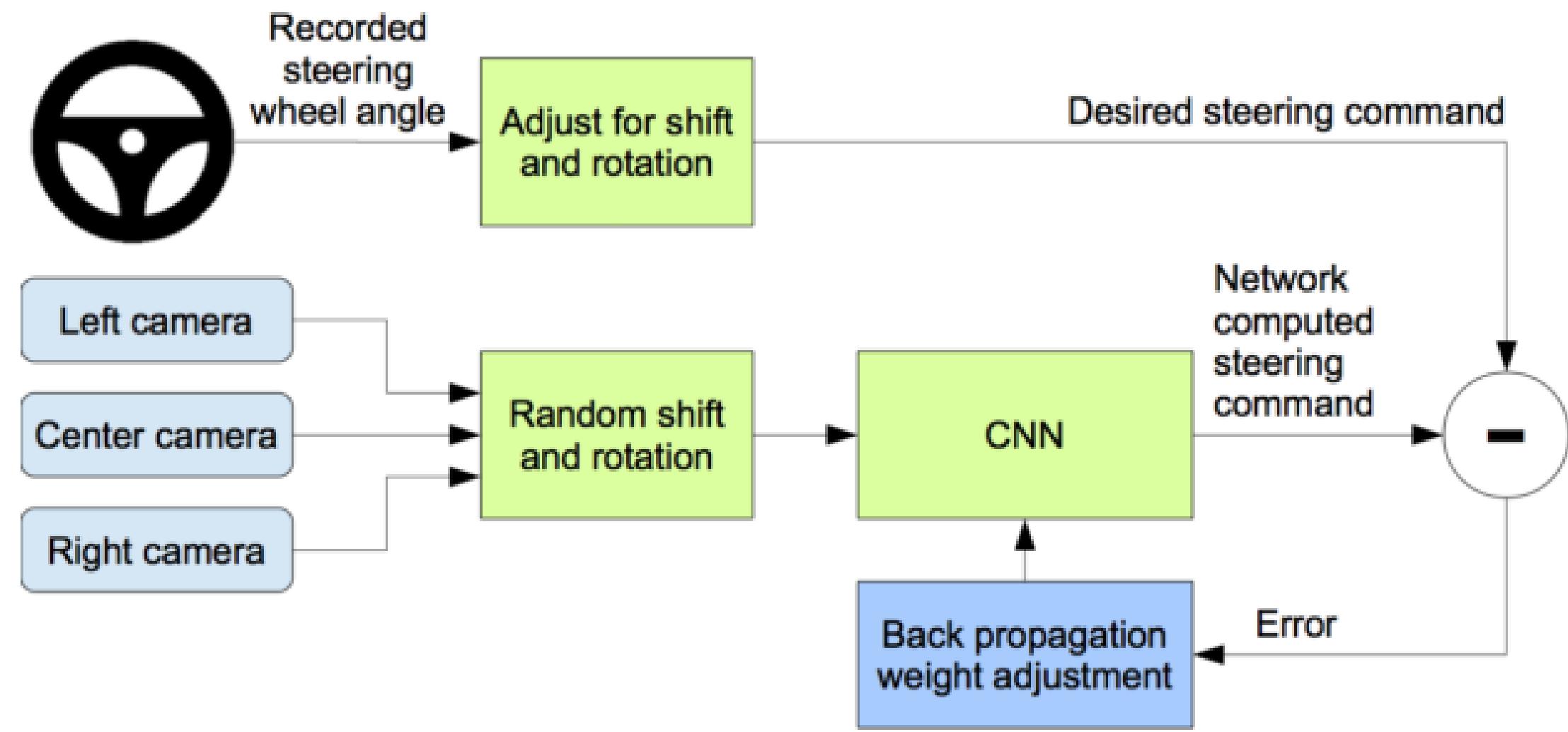
Semantic segmentation



Dave2 : NVIDIA's self-driving car



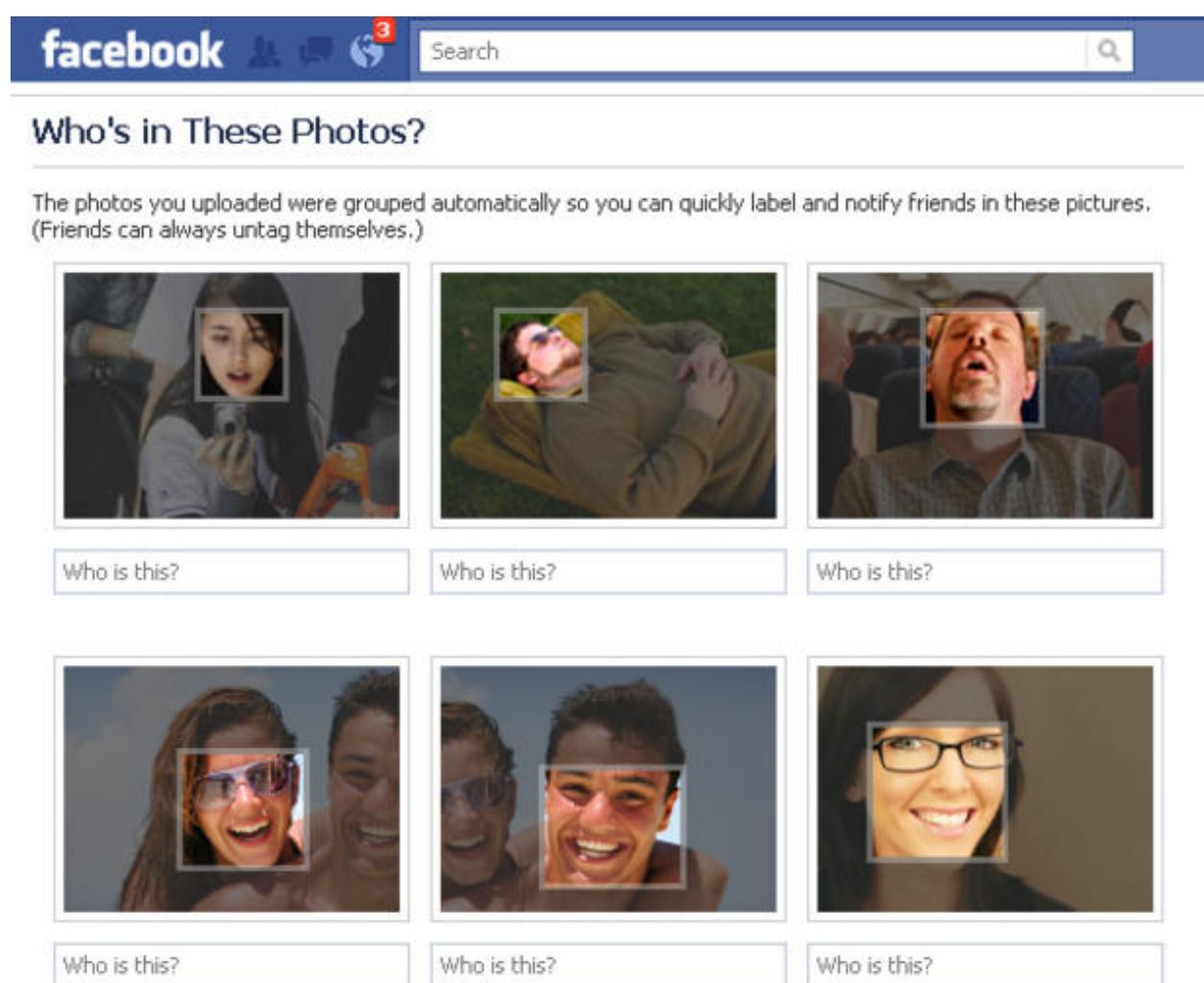
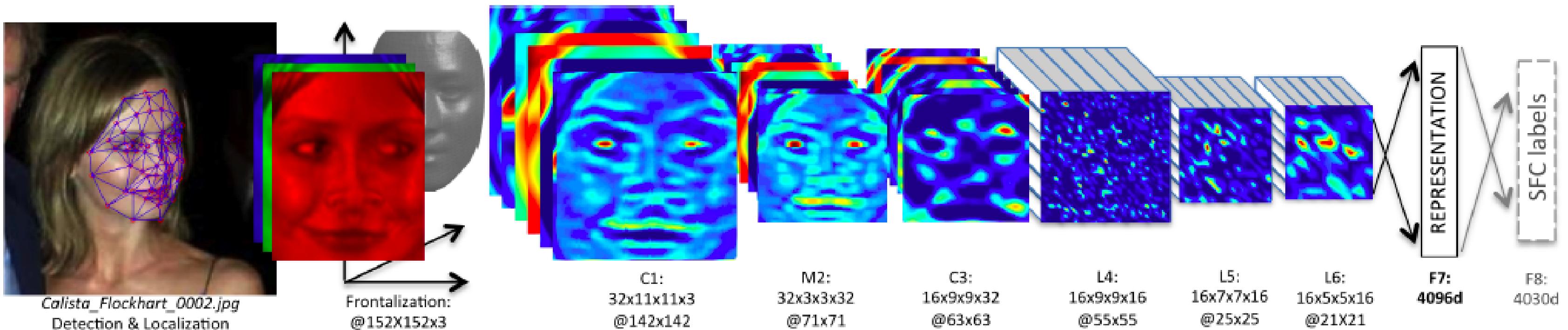
- NVIDIA trained a CNN to reproduce wheel steerings from experienced drivers using only a front camera.
- After training, the CNN took control of the car.



Dave2 : NVIDIA's self-driving car

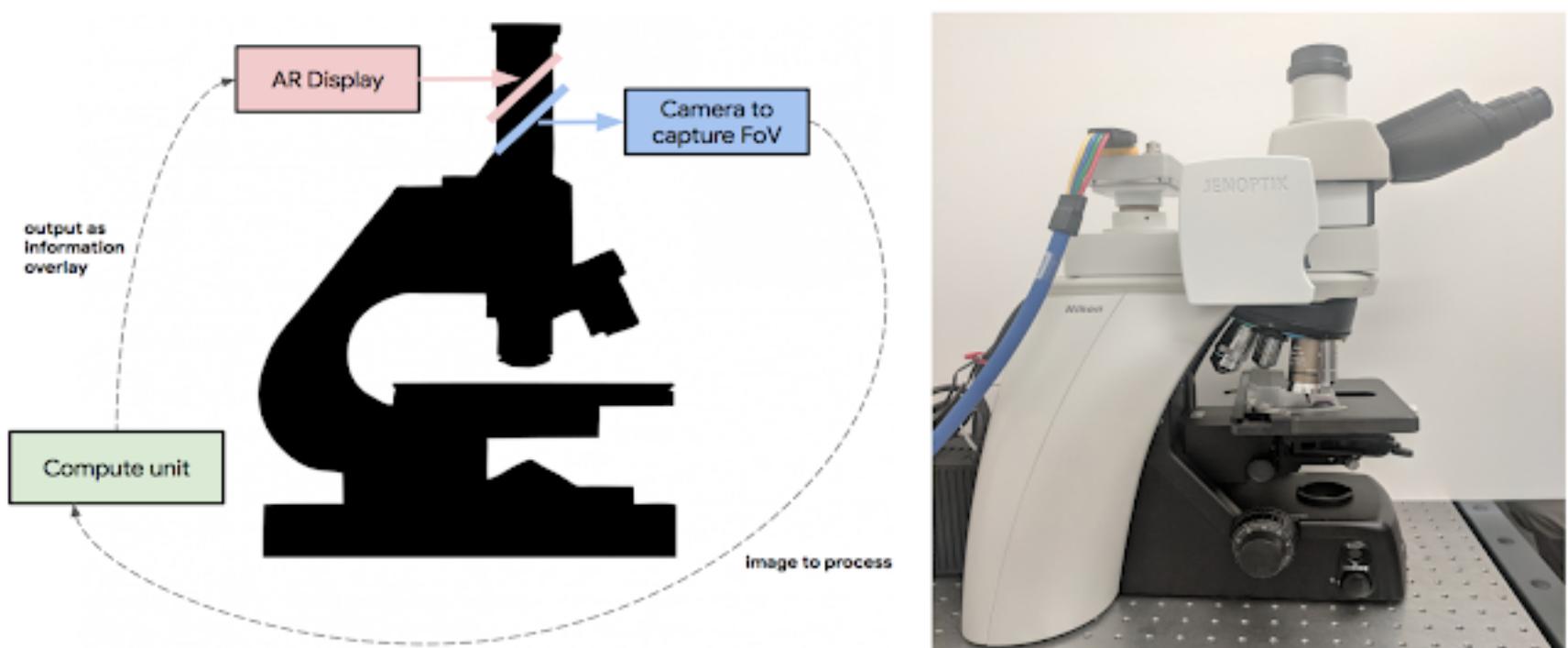
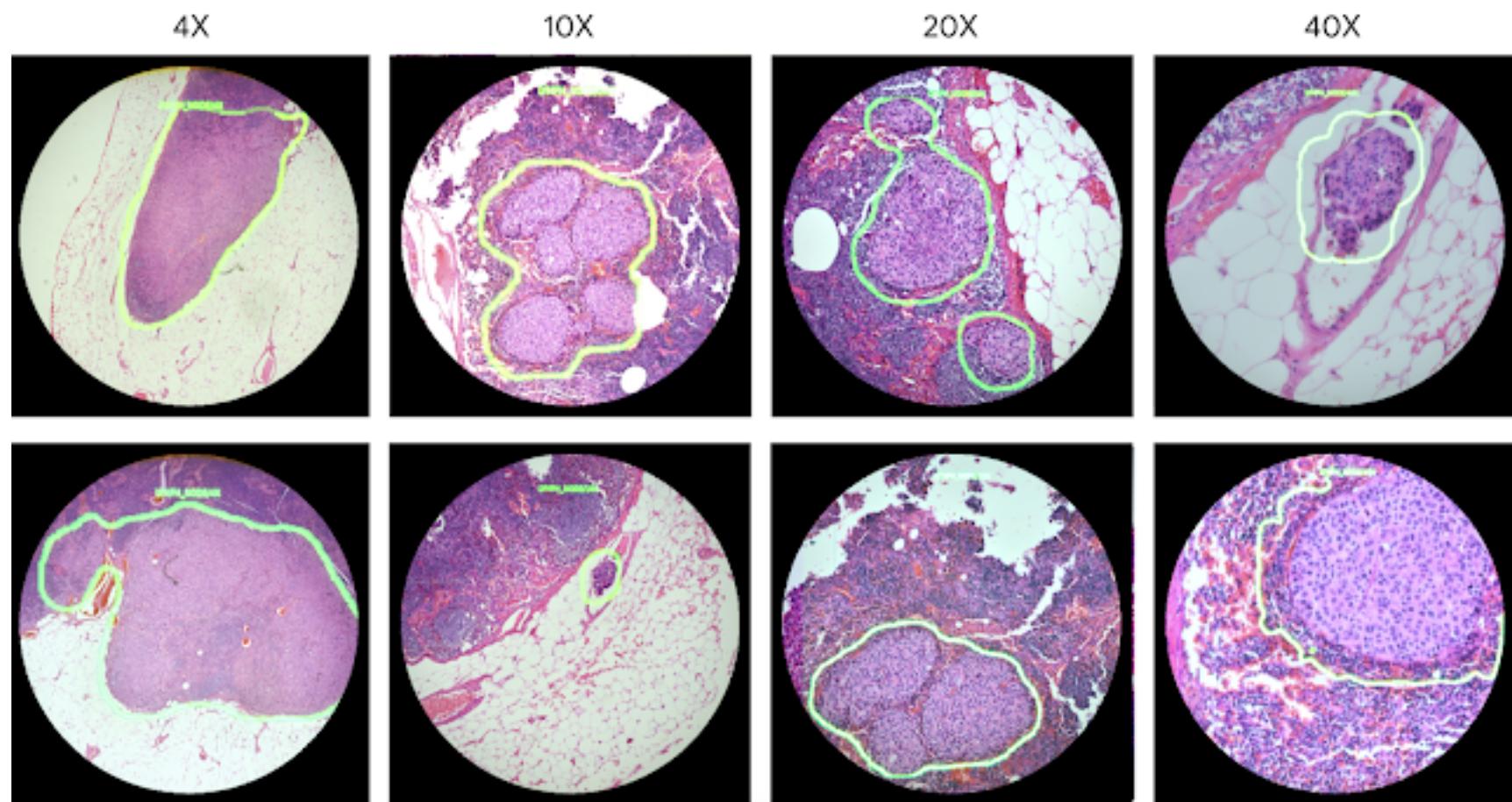


Facial recognition



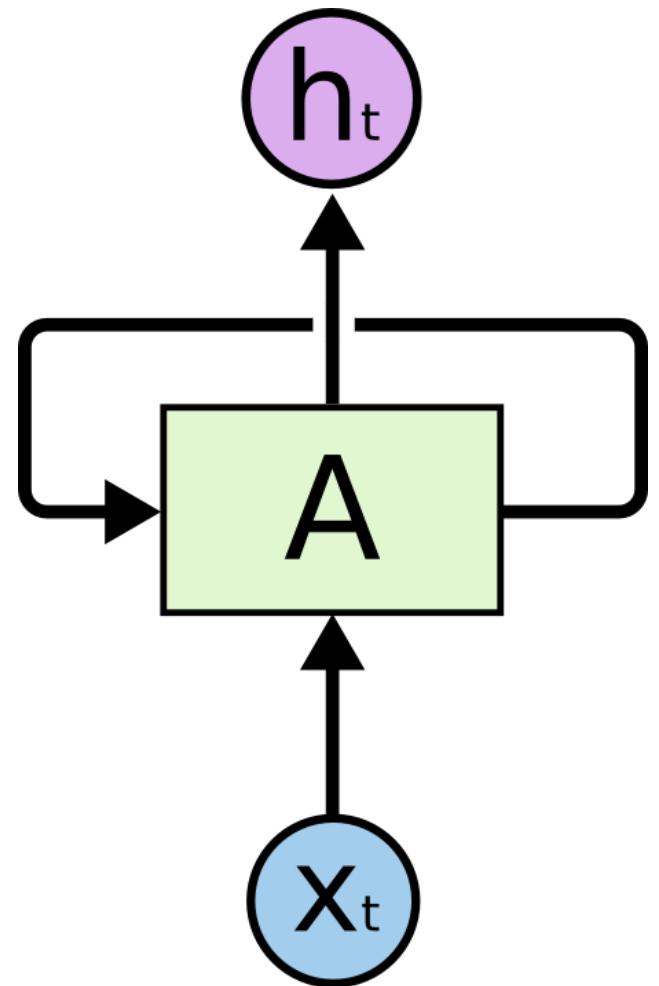
- Facebook used 4.4 million annotated faces from 4030 users to train **DeepFace**.
- Accuracy of 97.35% for recognizing faces, on par with humans.
- Used now to recognize new faces from single examples (transfer learning, one-shot learning).

Augmented Reality Microscope for Real-time Automated Detection of Cancer



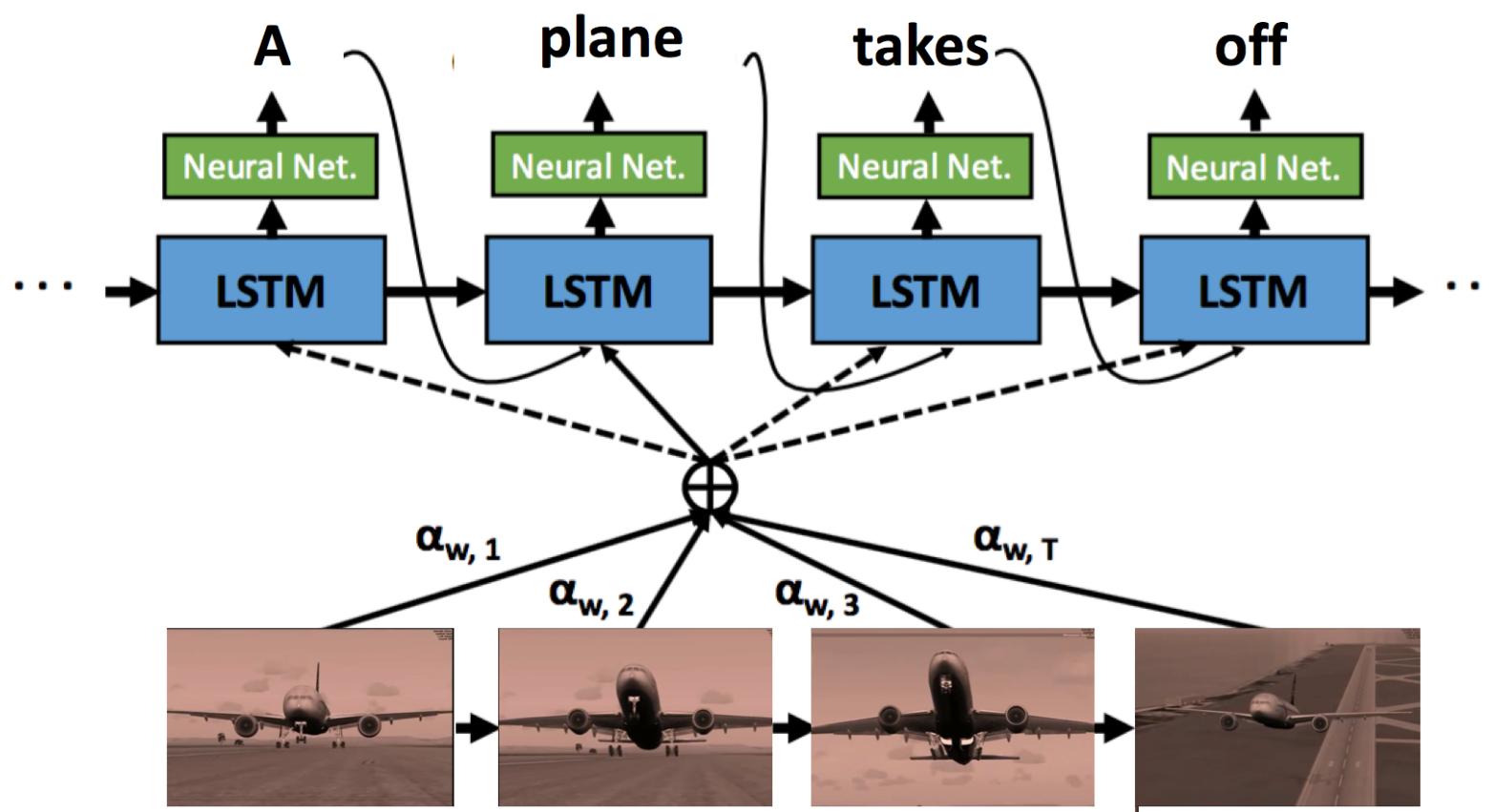
Recurrent neural networks

Recurrent neural networks

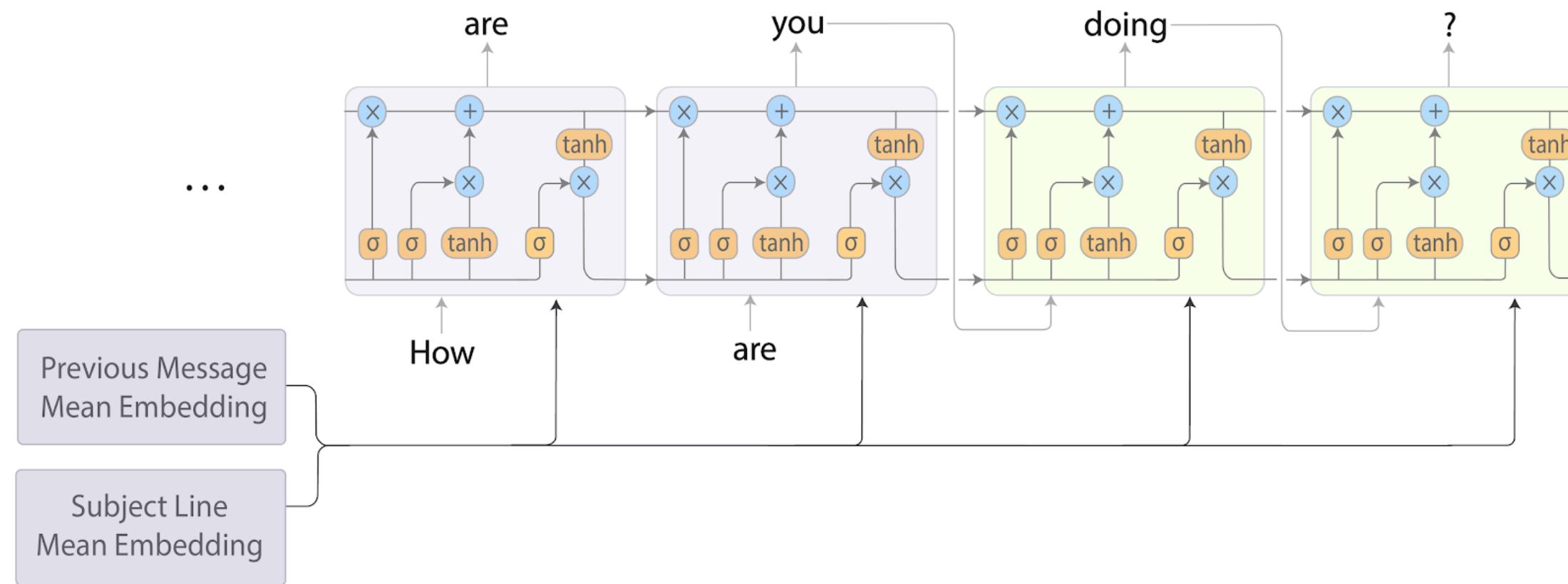


Source: C. Olah

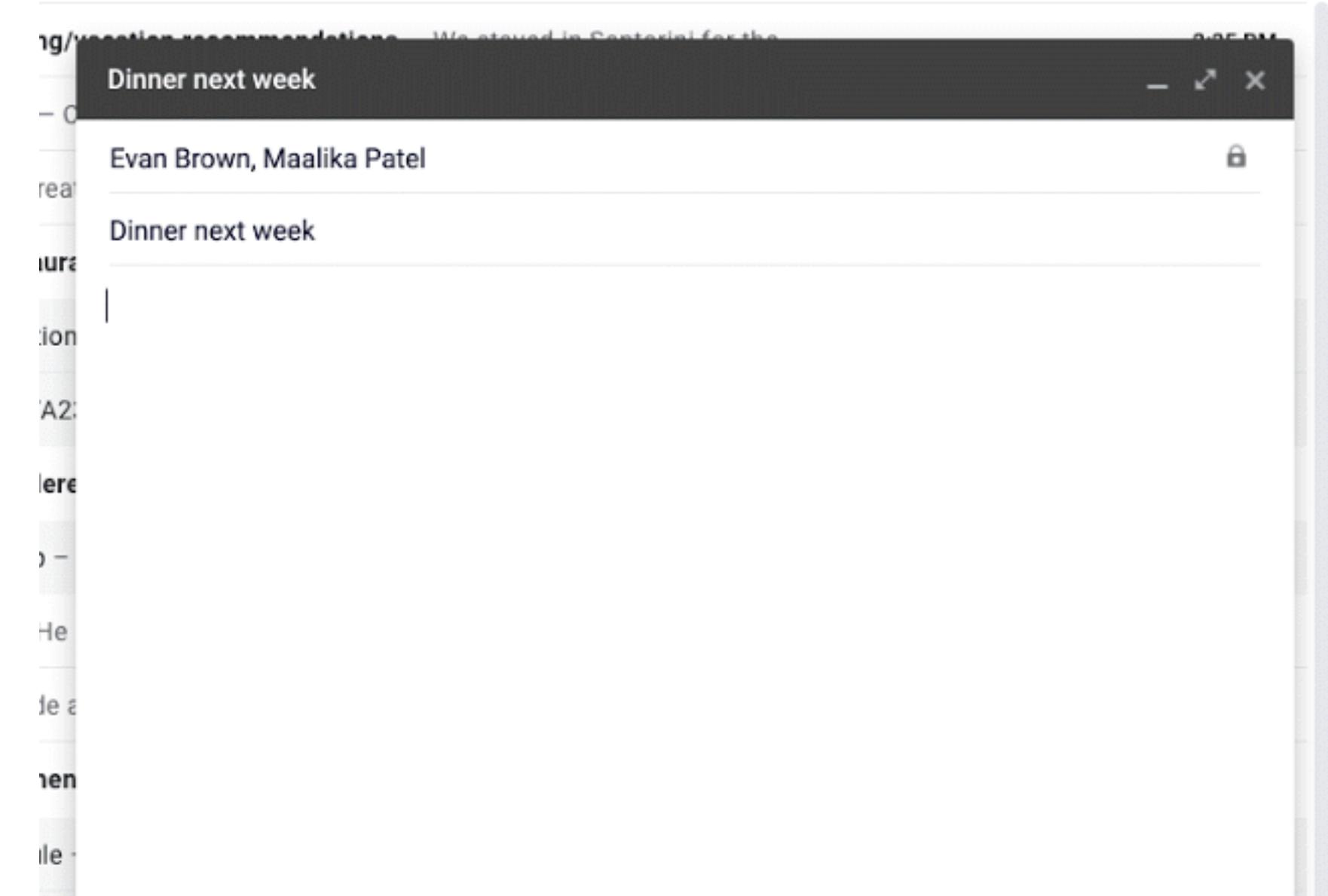
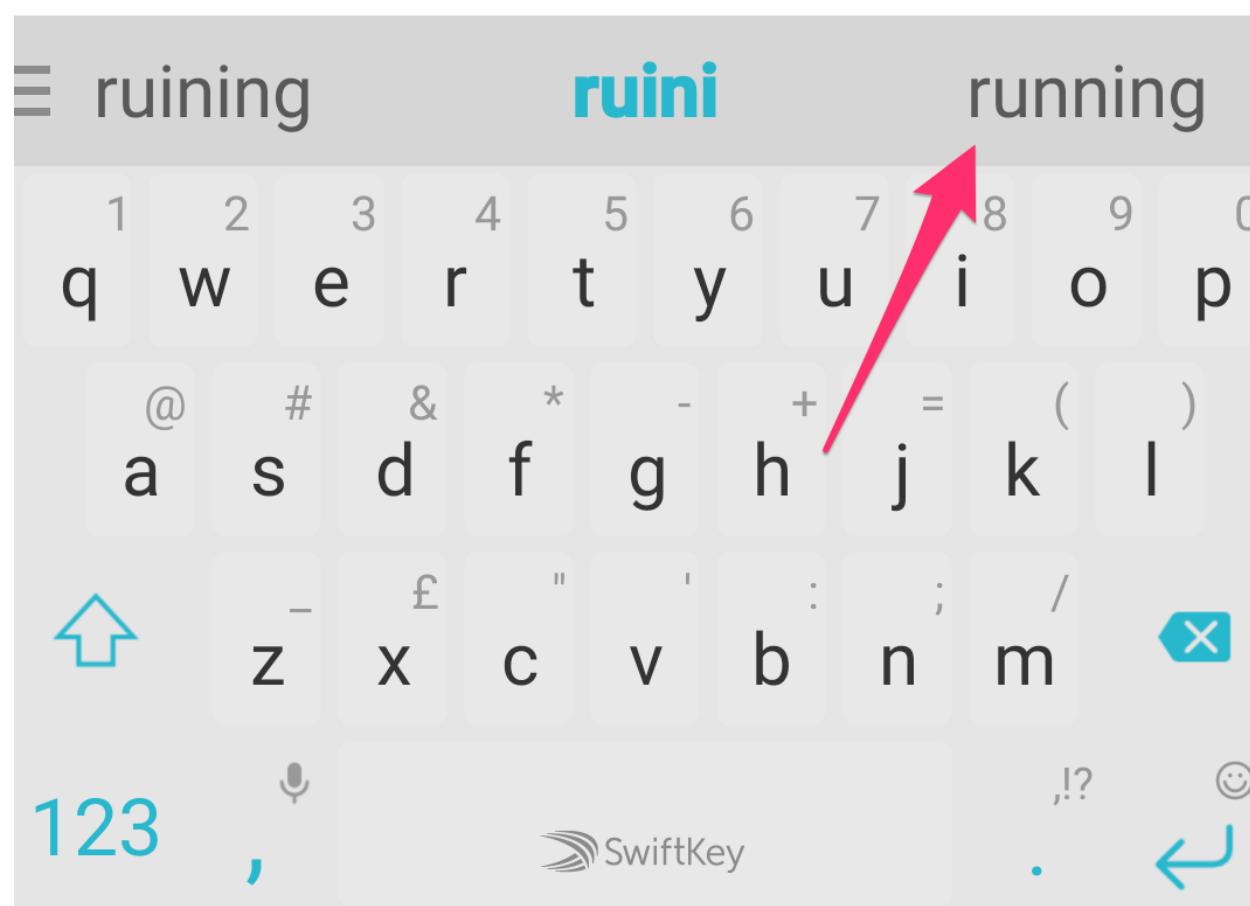
- A **recurrent neural network (RNN)** uses its previous output as an additional input (**context**).
- The inputs are integrated over time to deliver a response at the correct moment.
- This allows to deal with time series (texts, videos) without increasing the input dimensions.
- The input to the RNN can even be the output of a pre-trained CNN.
- The most efficient RNN is called **LSTM** (Long short-term memory networks) (Hochreiter and Schmidhuber, 1997).



Natural Language Processing : Automatic word/sentence completion



Hey hope you had a good day! Do
you want to go ruini



Natural Language Processing : Text Generation

PANDARUS:

Alas, I think he shall be come approached and the day
When little strain would be attain'd into being never
fed,
And who is but a chain and subjects of his death,
I should not sleep.

Second Senator:

They are away this miseries, produced upon my soul,
Breaking and strongly should be buried, when I perish
The earth and thoughts of many states.

DUKE VINCENTIO:

Well, your wit is in the care of side and that.

Second Lord:

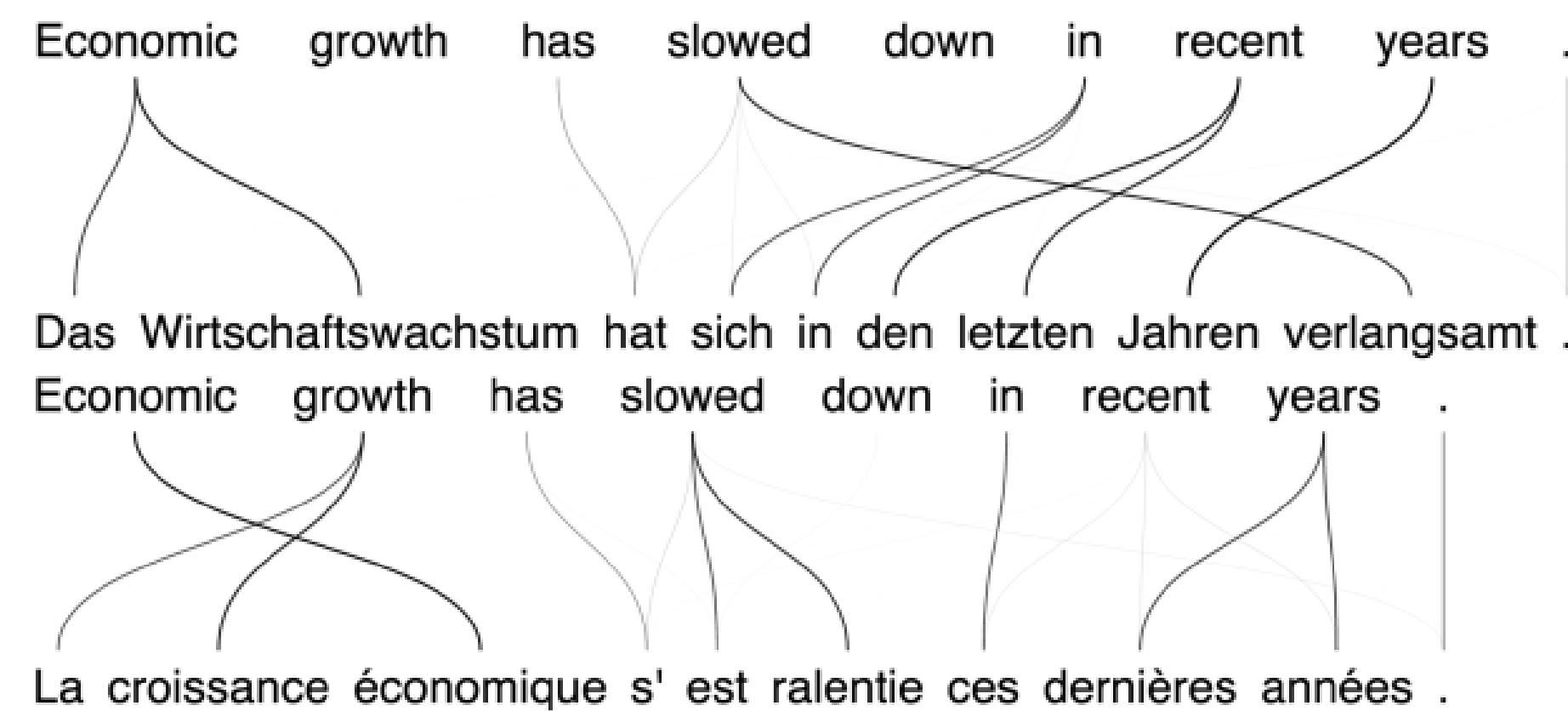
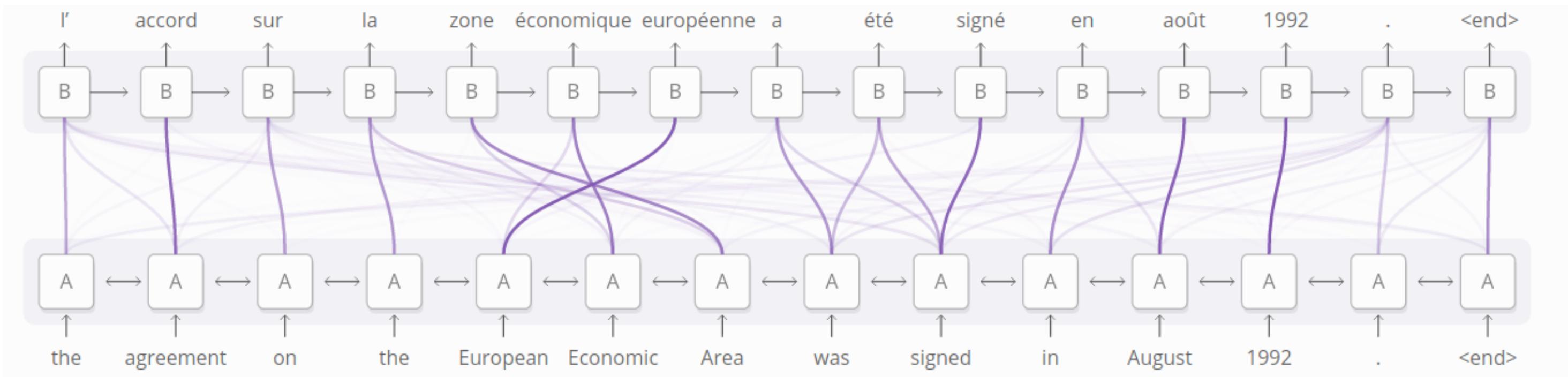
They would be ruled after this chamber, and
my fair nues begun out of the fact, to be conveyed,
Whose noble souls I'll have the heart of the wars.

Clown:

Come, sir, I will make did behold your worship.

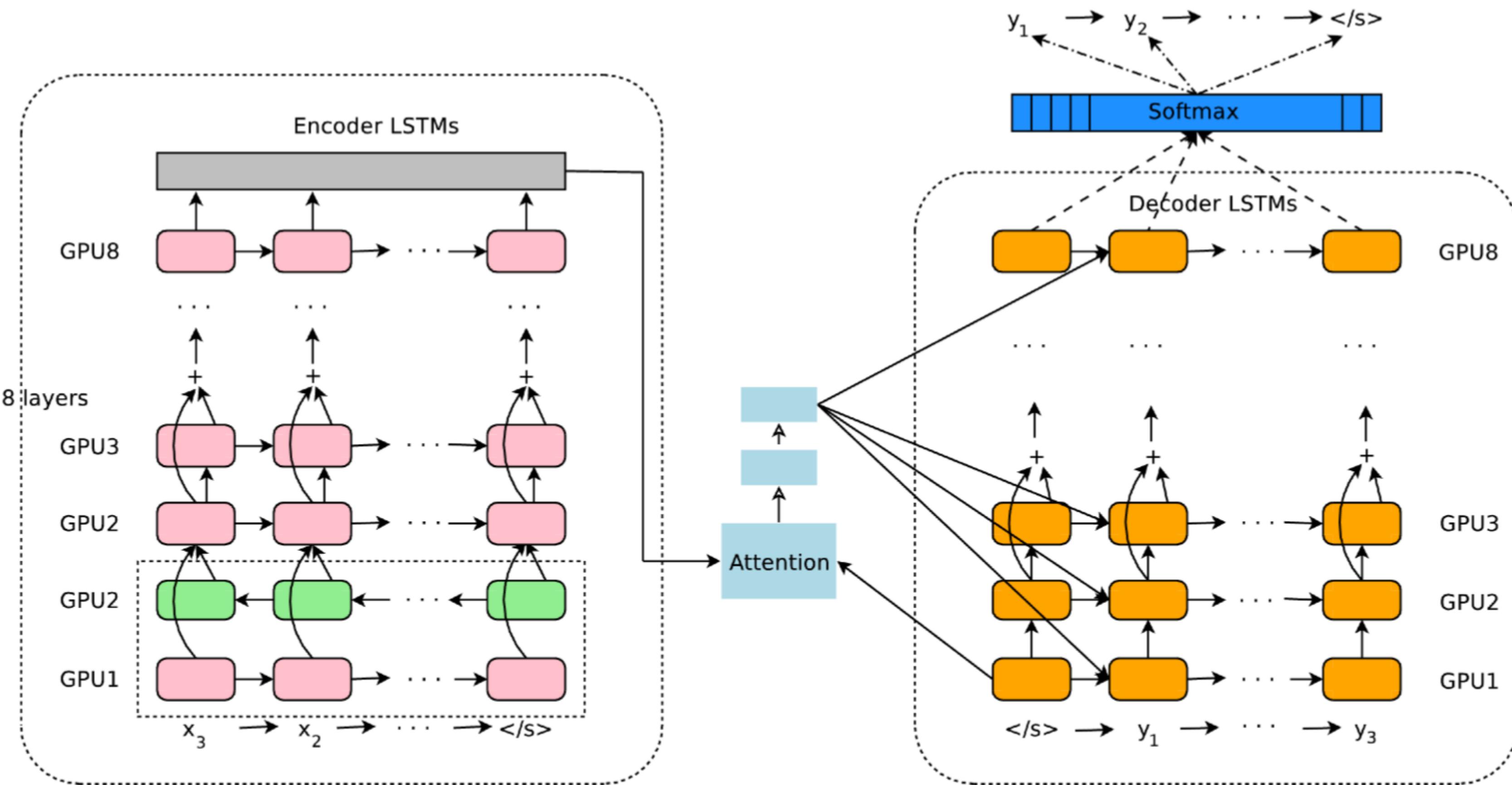
- Characters or words are fed one by one into a LSTM.
- The desired output is the next character or word in the text.
- Example:
 - Inputs: **To, be, or, not, to**
 - Output: **be**
- The text on the left was generated by a LSTM having read the entire writings of William Shakespeare.
- Each generated word is used as the next input.

Natural Language Processing : text translation



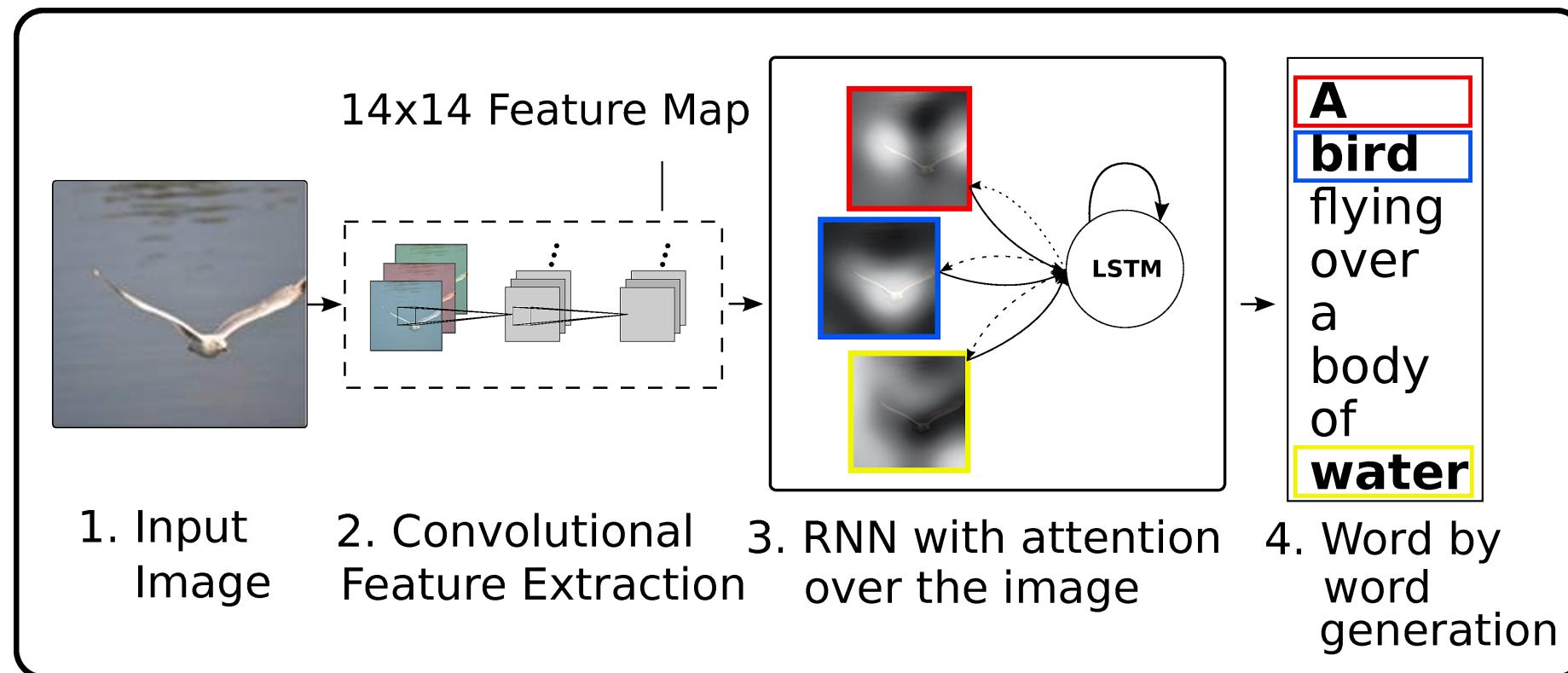
- Two LSTM can be stacked to perform sequence-to-sequence translation (**seq2seq**).
- One is the encoder, the other the decoder.

Natural Language Processing : Google Neural Machine Translation



- Same idea, but with much more layers...
- Can translate any pair of languages!

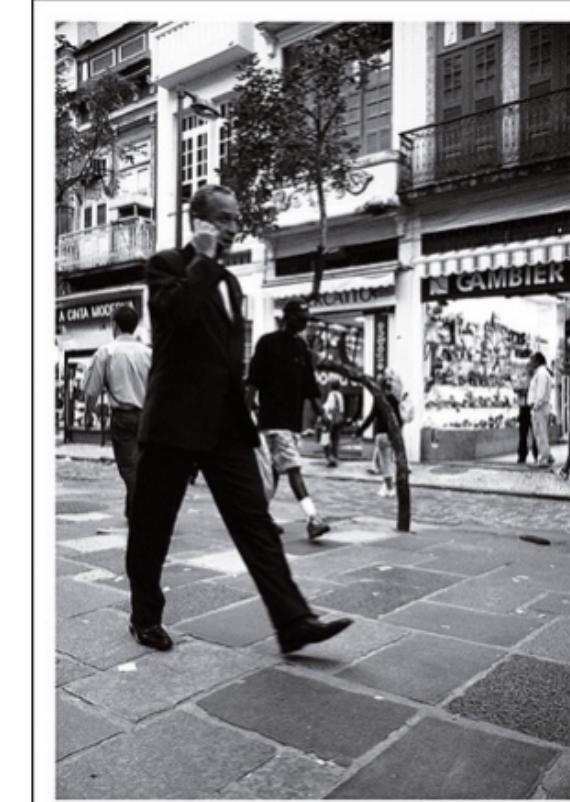
Caption Generation



↑ a living room with a couch and a television

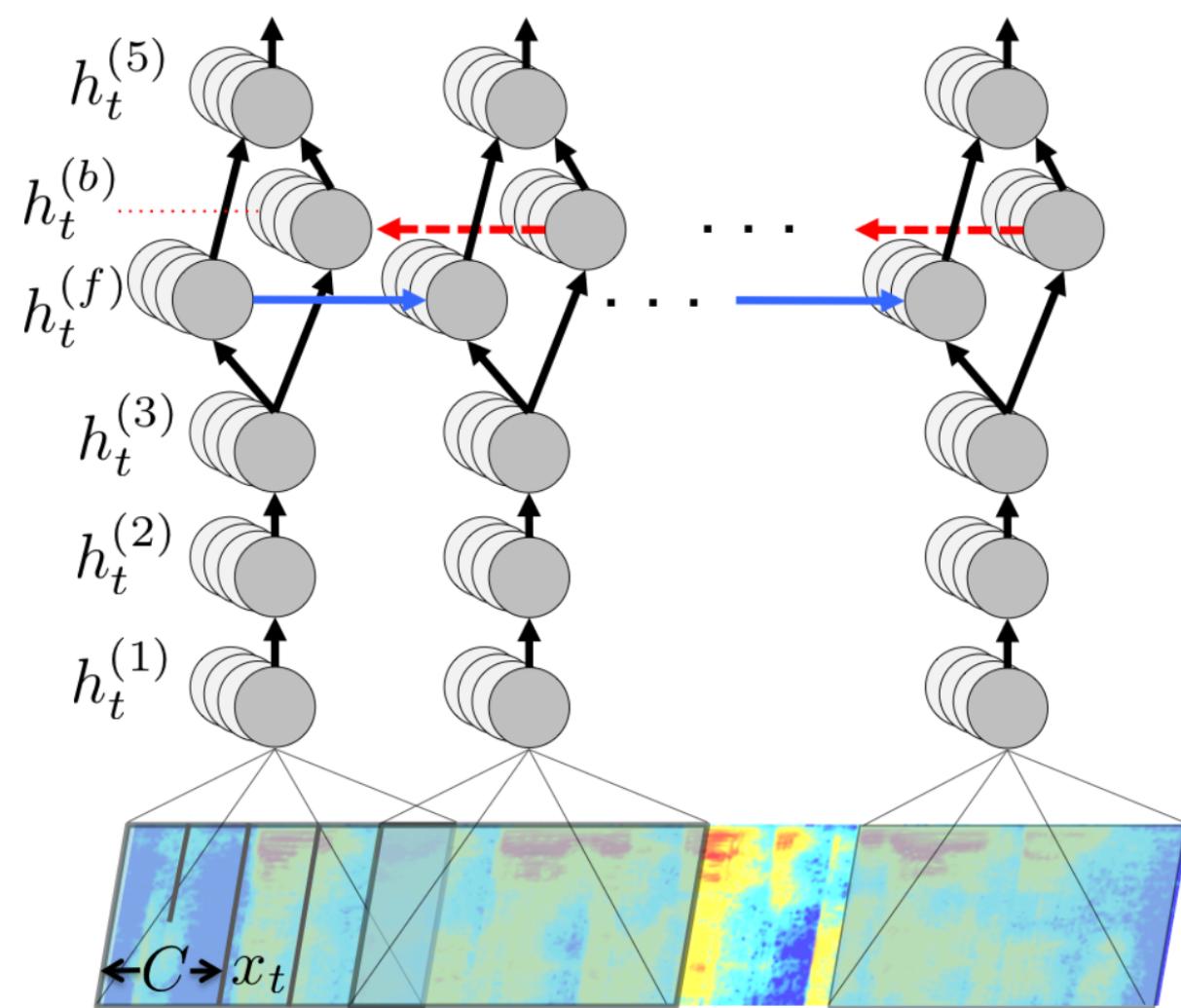
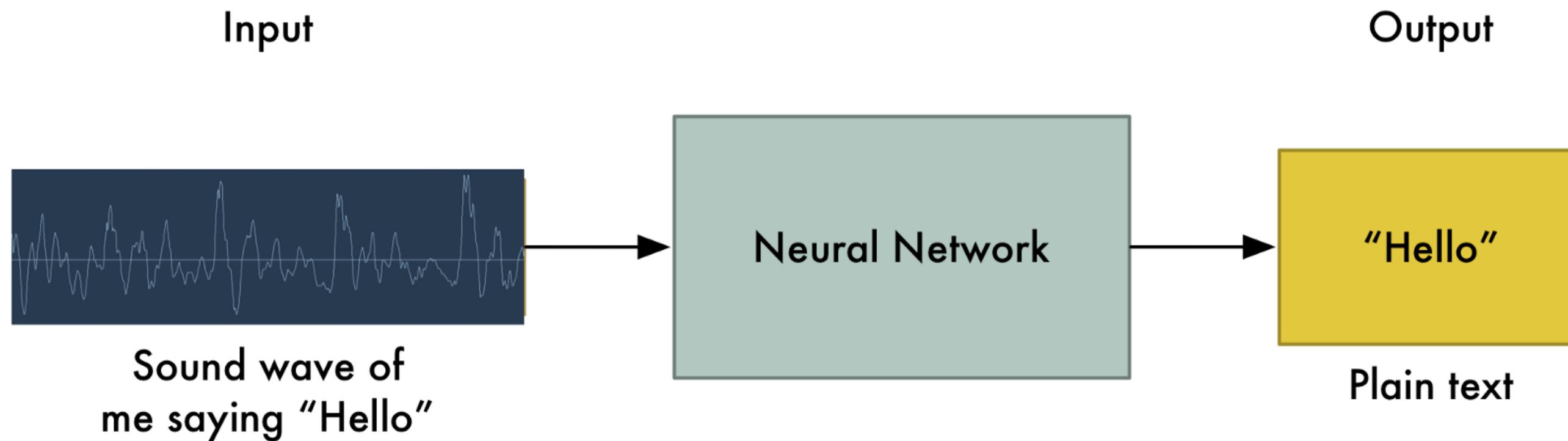


↑ a man riding a bike on a beach



a man is walking down the street with a suitcase ↗

Voice recognition

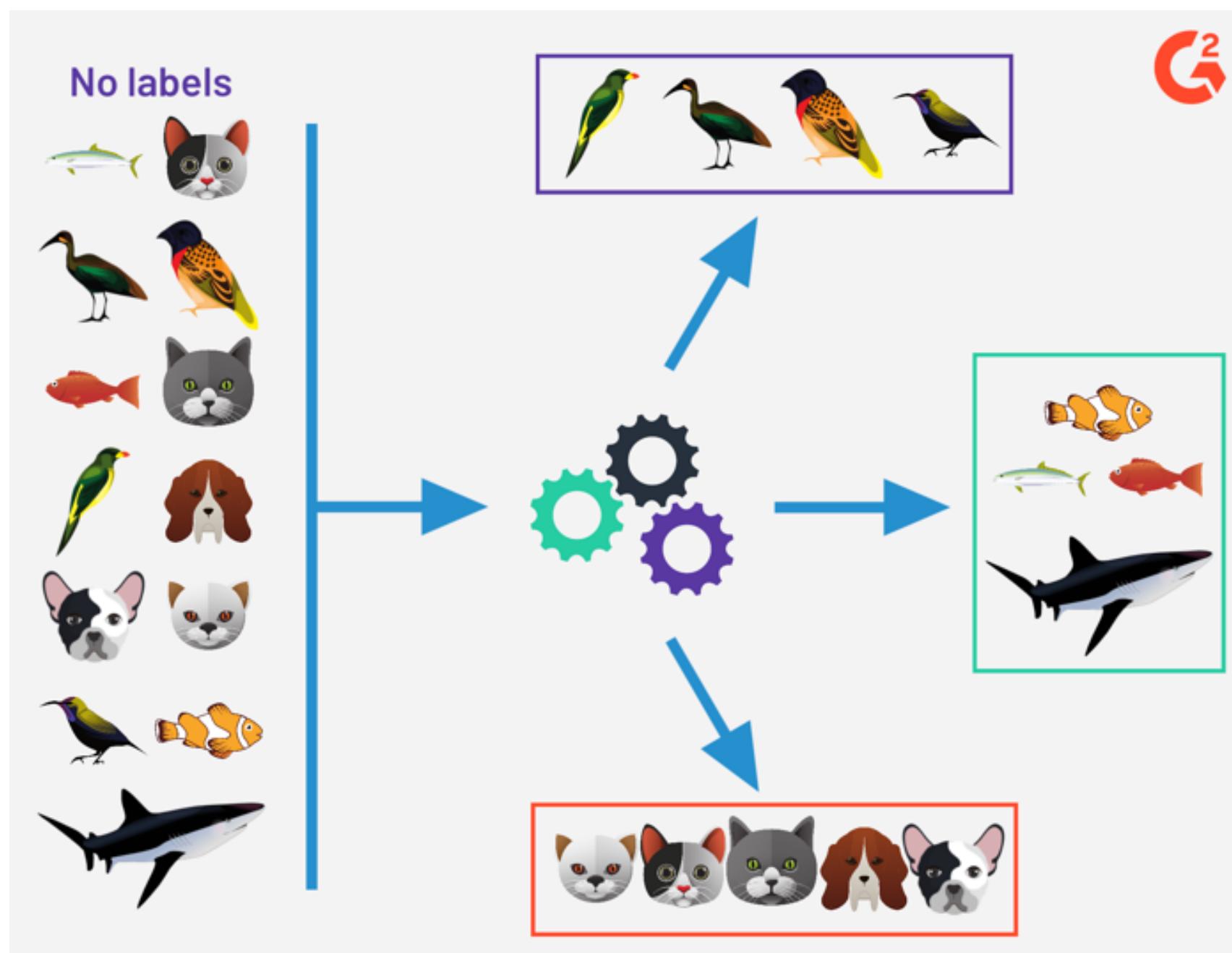


- CNNs are not limited to images, voice signals can also be recognized using their mel-spectrum.
- Siri, Alexa, Google now, etc. use recurrent CNNs to recognize vocal commands and respond.
- **DeepSpeech** from Baidu is one of the state-of-the-art approaches.

2 - Unsupervised learning

Unsupervised learning

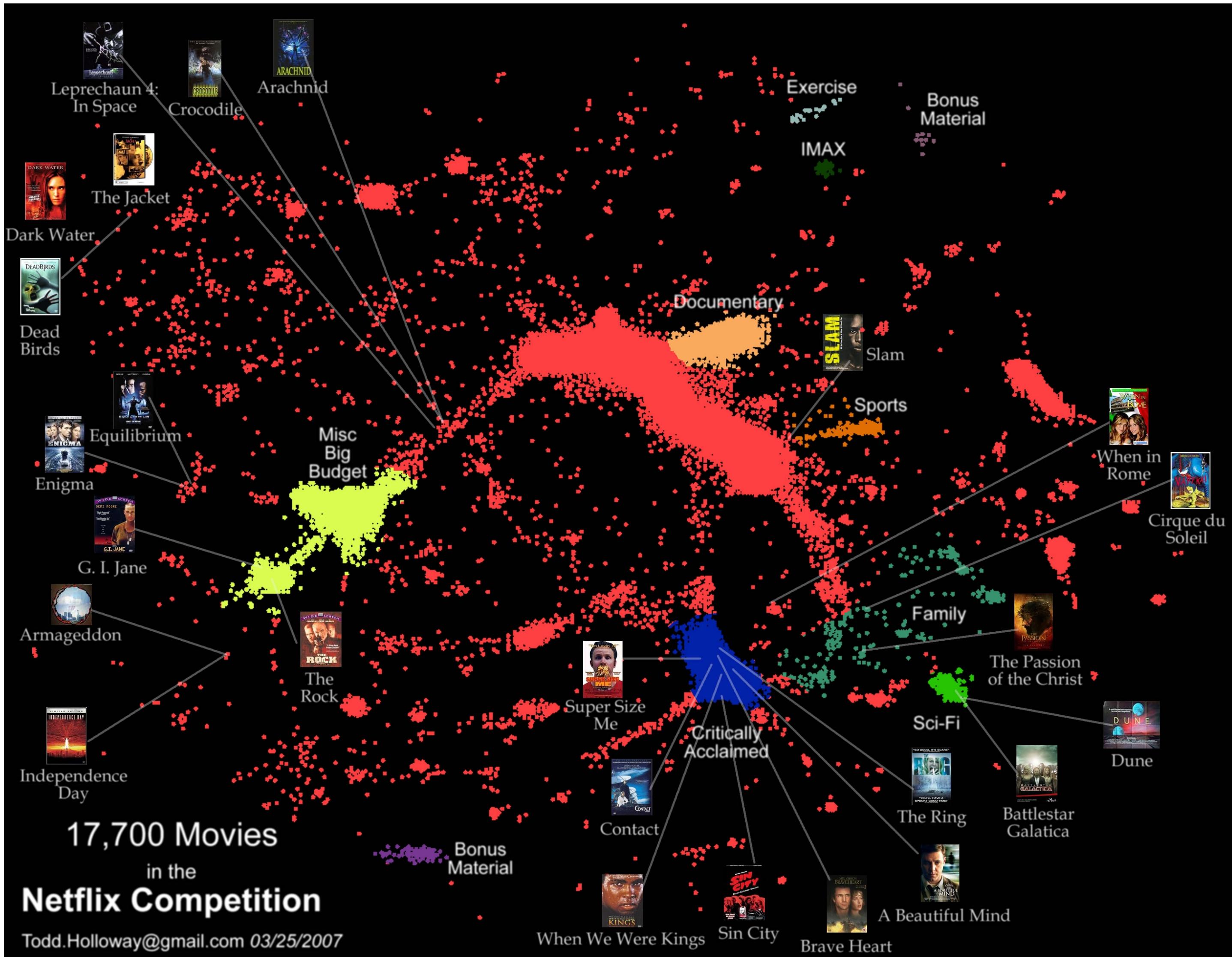
- In unsupervised learning, only raw input data is provided to the algorithm, which has to analyze the statistical properties of the data.



<https://learn.g2.com/supervised-vs-unsupervised-learning>

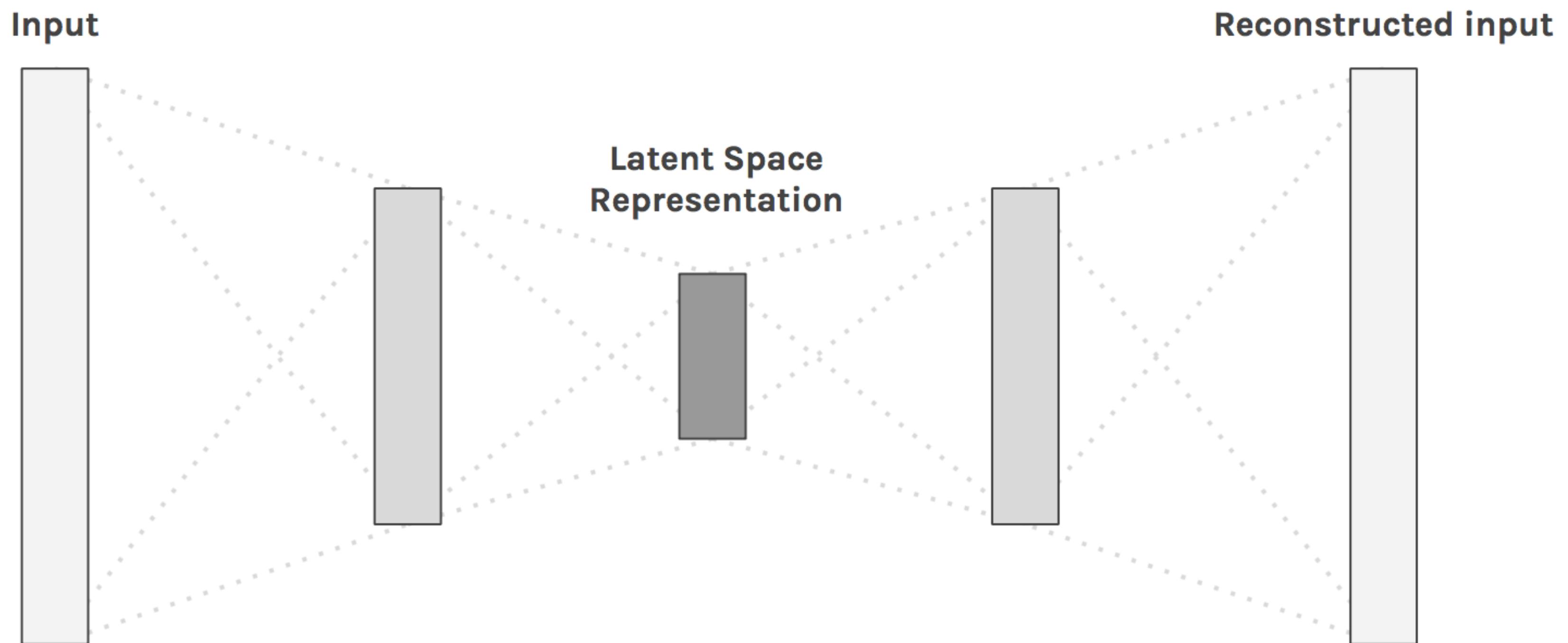
- The goal of **unsupervised learning** is to build a model or find useful representations of the data, for example:
 - finding groups of similar data and model their density (**clustering**).
 - reduce the redundancy of the input dimensions (**dimensionality reduction**).
 - finding good explanations / representations of the data (**latent data modeling**).
 - generate new data (**generative models**).

Clustering: learning topologies in film preferences



Dimensionality reduction: finding the right latent space

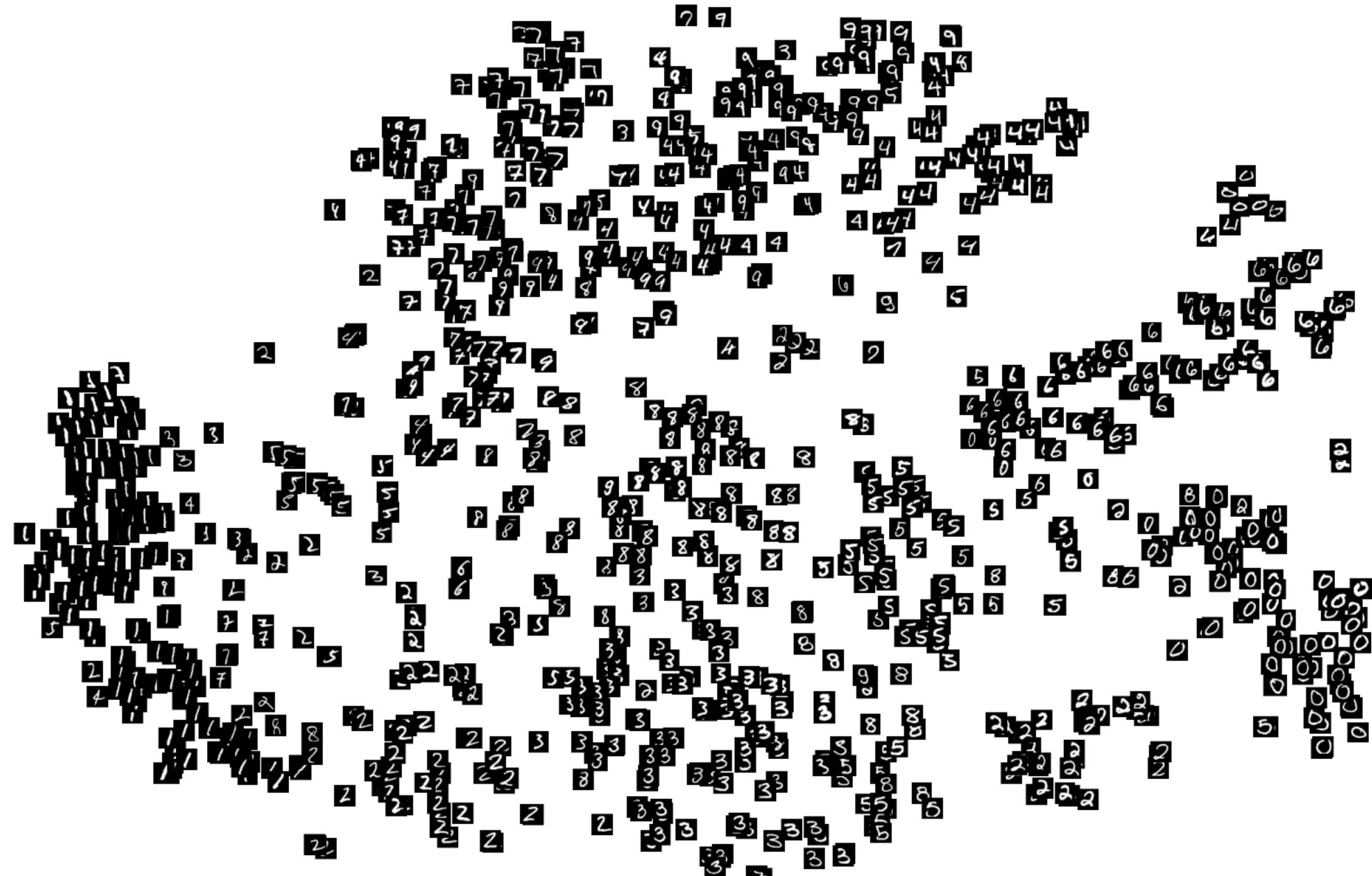
- Images have a lot of dimensions (pixels), most of which are redundant.
- Dimensionality reduction techniques allow to reduce this number of dimensions by projecting the data into a **latent space**.
- **Autoencoders** are NN that learn to reproduce their inputs by compressing information through a bottleneck.



<https://hackernoon.com/autoencoders-deep-learning-bits-1-11731e200694>

Dimensionality reduction: visualization

- If the latent space has two or three dimensions, you can use dimensionality reduction to **visualize** your data.

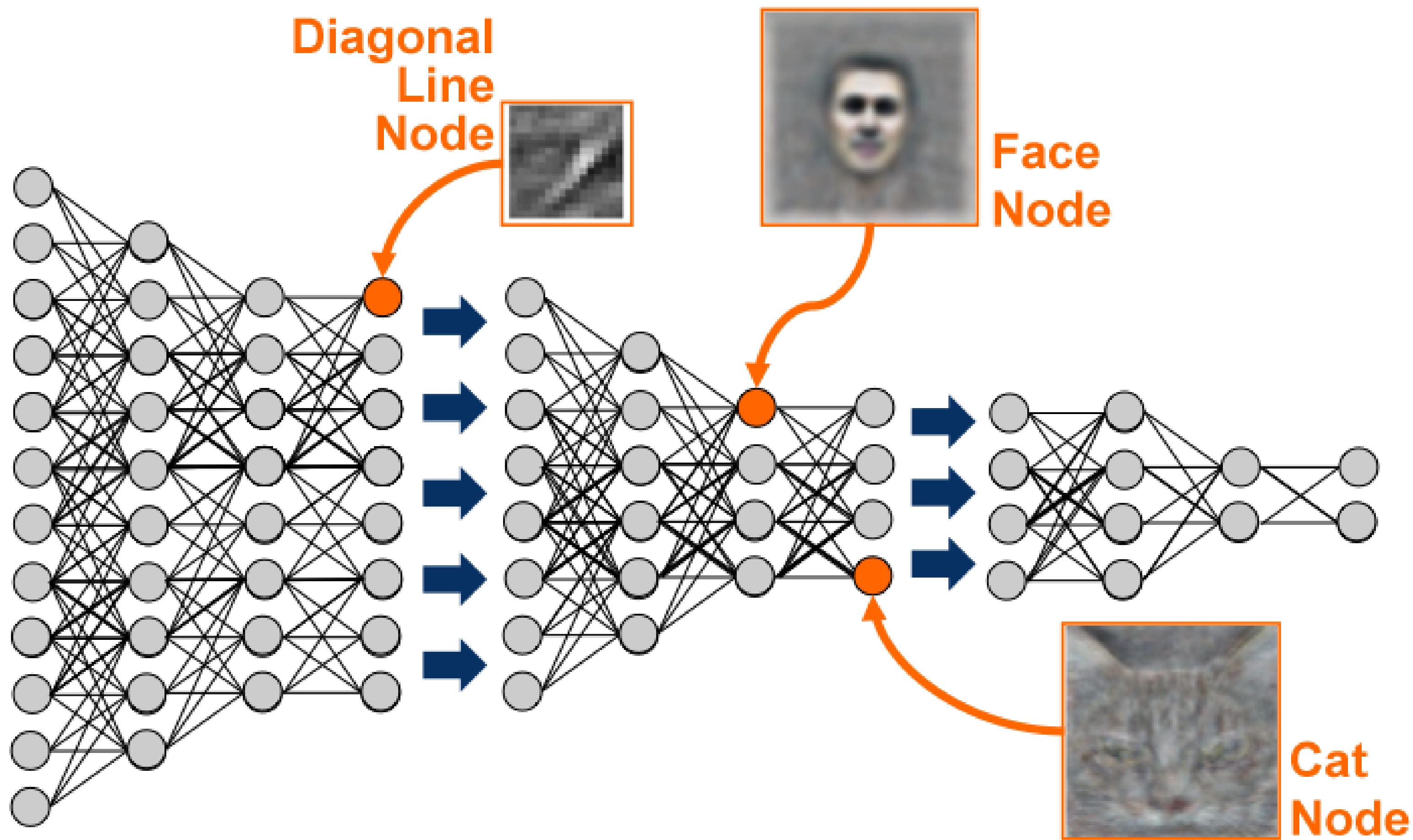


<https://hackernoon.com/latent-space-visualization-deep-learning-bits-2-bd09a46920df>

- Classical machine learning algorithms include PCA (principal component analysis) or t-SNE.
- NN autoencoders can also be used for visualization, e.g. UMAP.

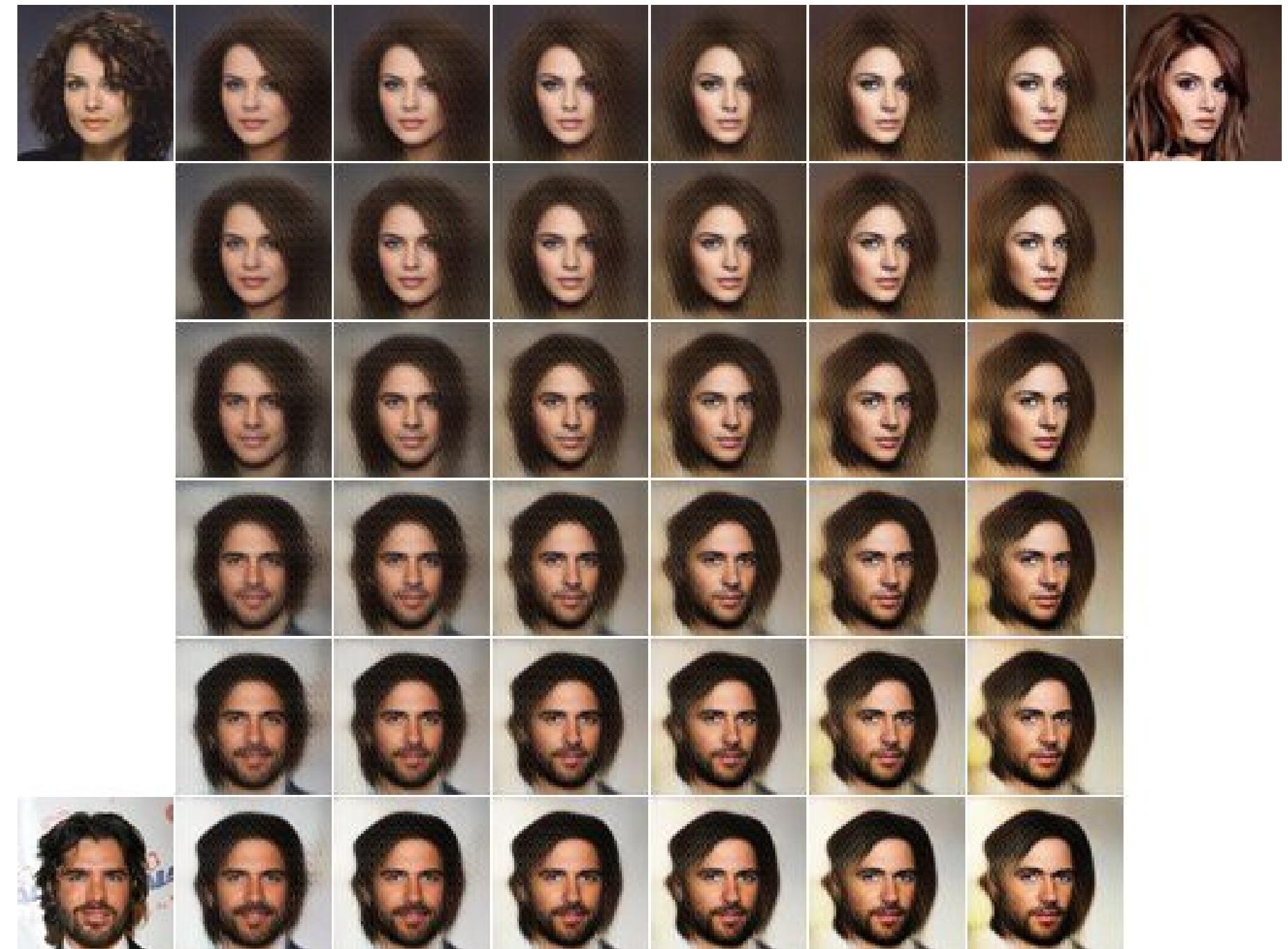
Feature extraction: self-taught learning

- **Pretrain** a neural network on huge unlabeled datasets (e.g. Youtube videos) before applying it to small-data supervised problems.



Generative models

- If the latent space is well organized, you can even sample from it to generate new images using **variational autoencoders (VAE)**.

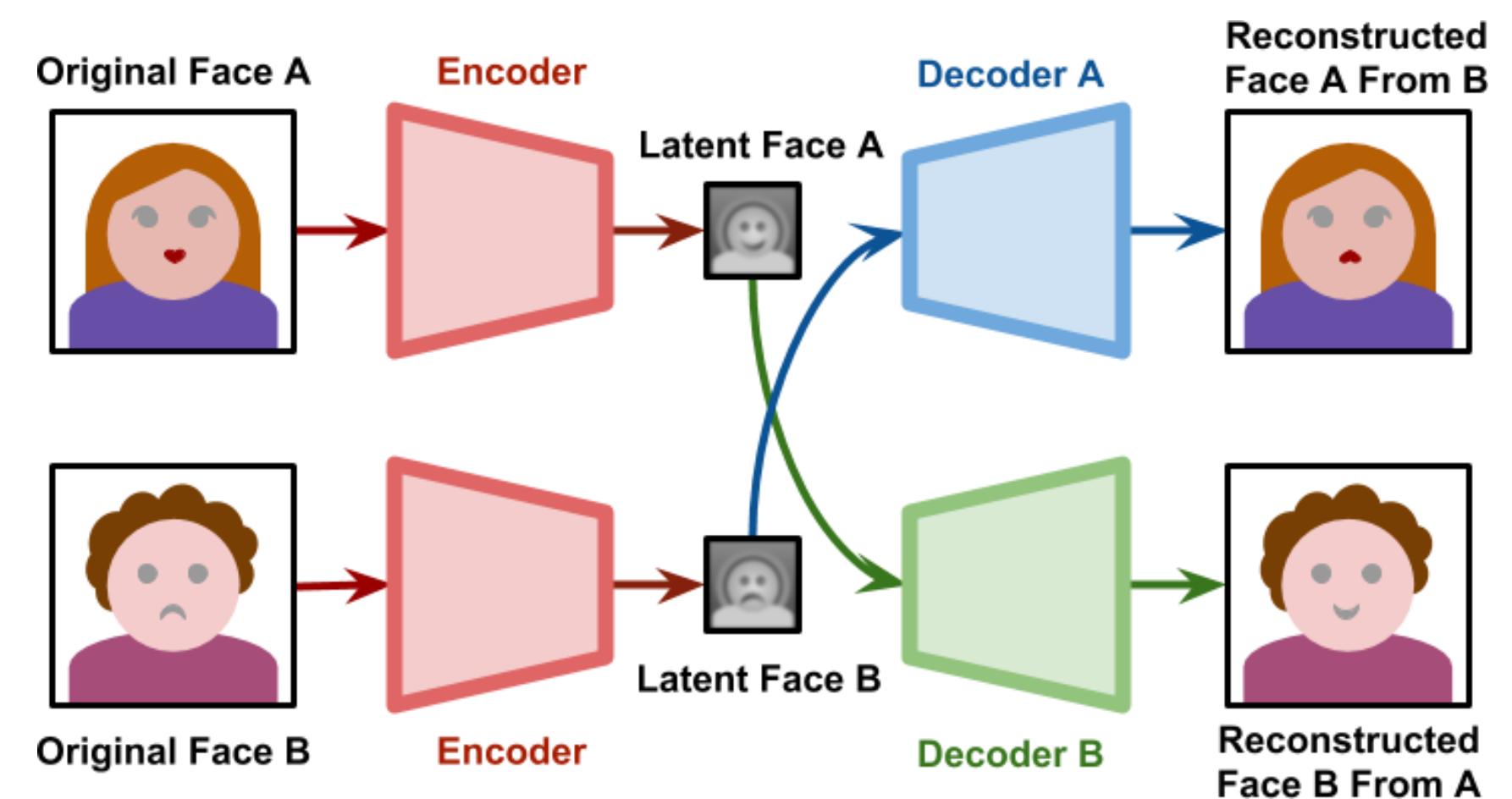
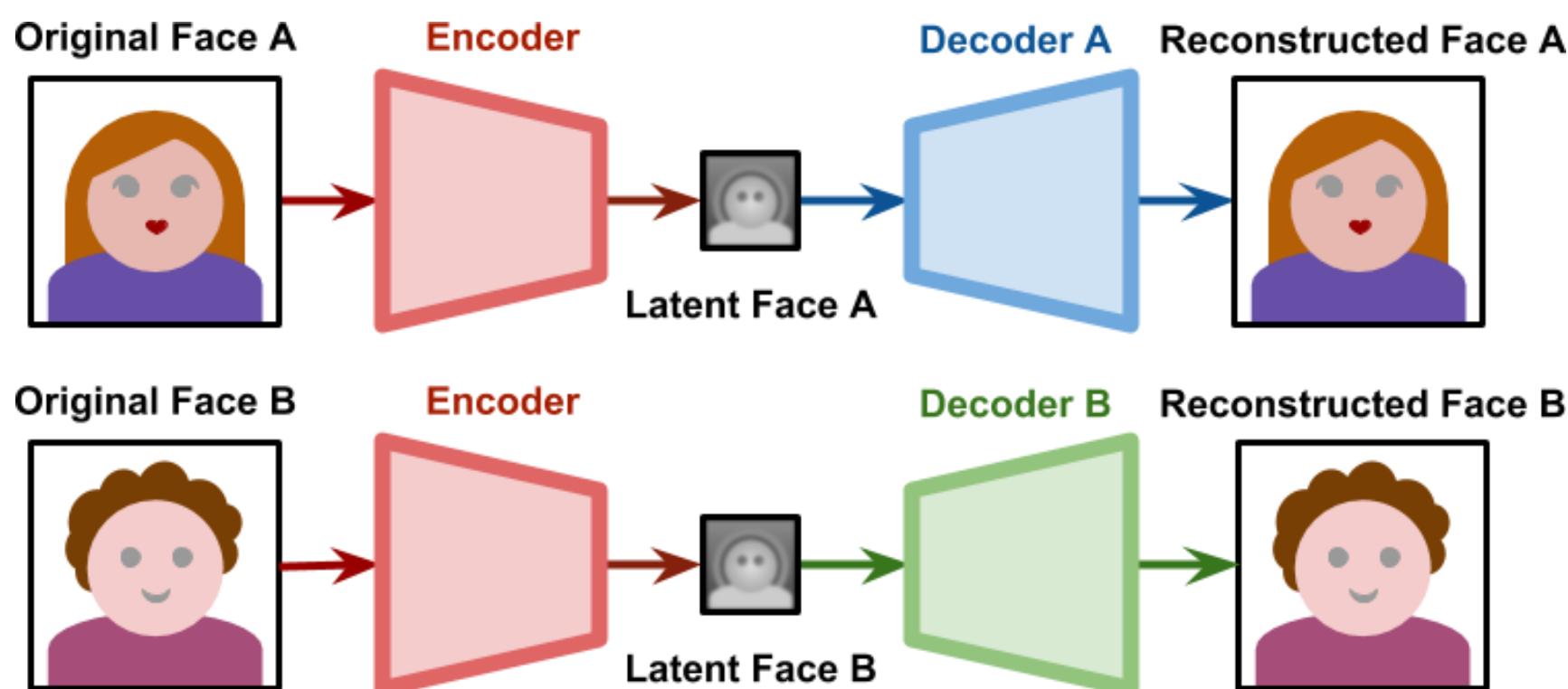


DeepFake

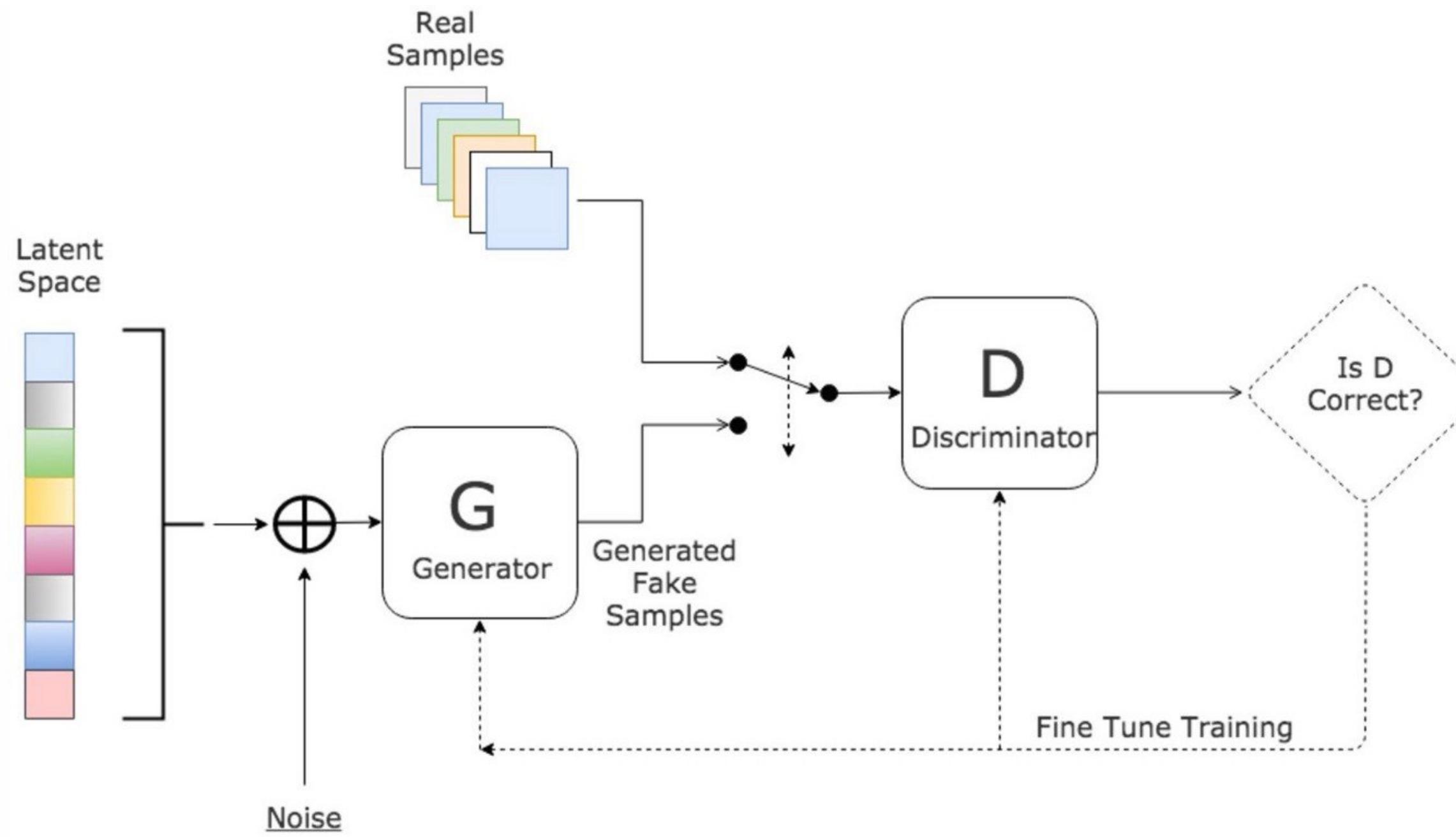


DeepFake

- During training, each autoencoder learns to reproduce the face of one person.
- When generating the deepfake, the decoder of person B is used on the encoder of person A.



Generative Adversarial Networks

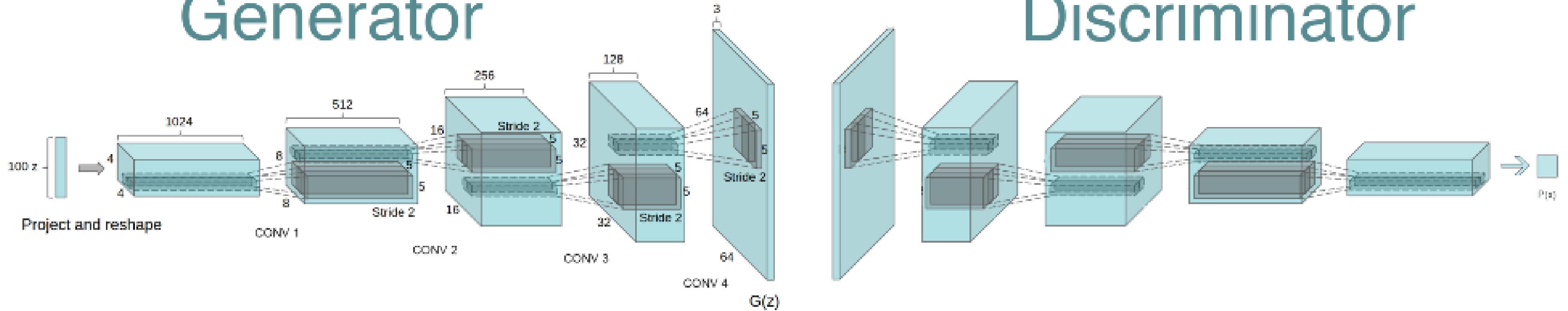


- A **Generative Adversarial Network (GAN)** is composed of two networks:
 - The **generator** learns to produce realistic images.
 - The **discriminator** learn to differentiate real data from generated data.
- Both compete to reach a Nash equilibrium:

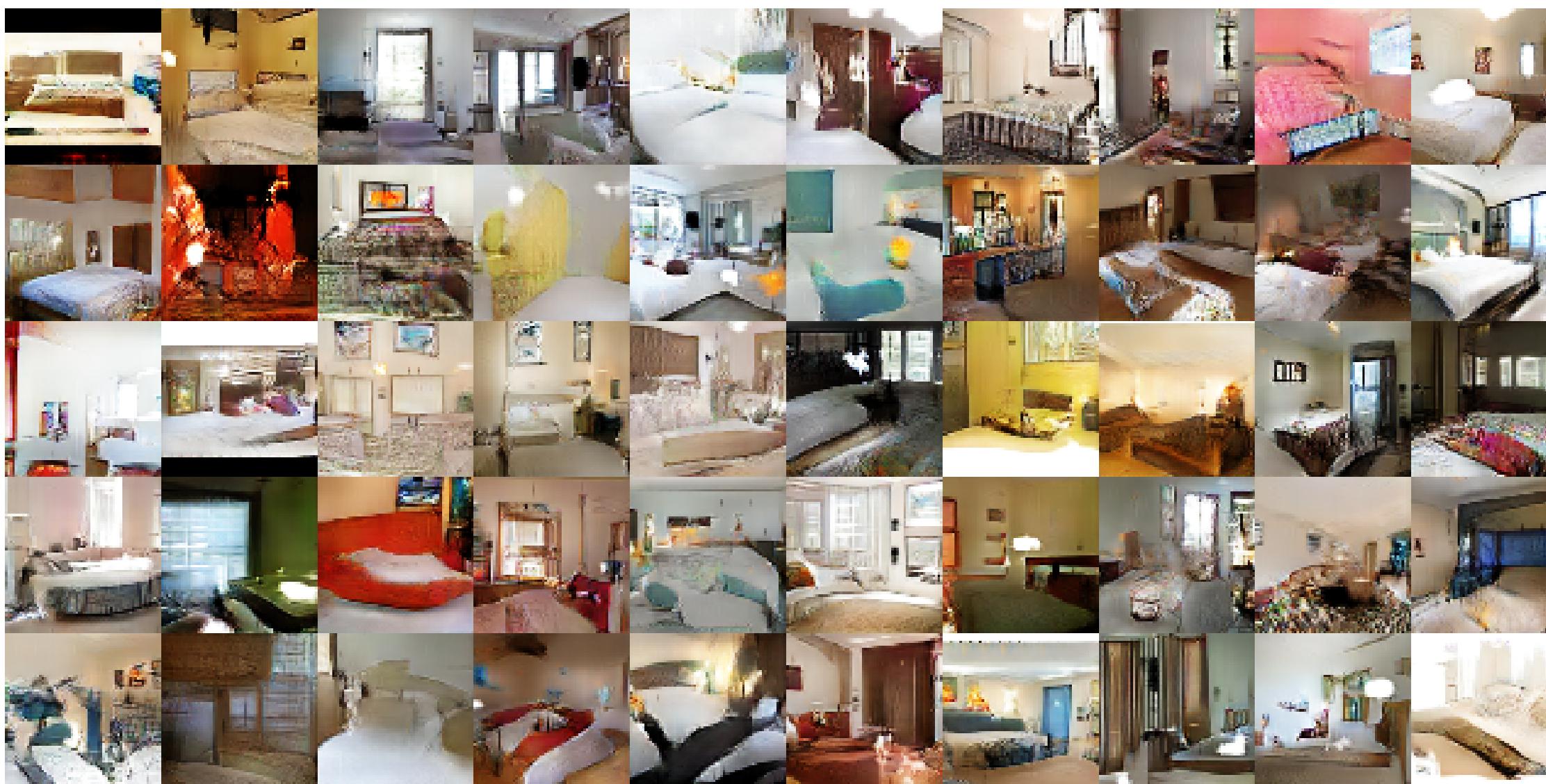
$$\min_G \max_D V(D, G) = \mathbb{E}_{x \sim P_{\text{data}}(x)} [\log D(x)] + \mathbb{E}_{z \sim P_z(z)} [\log(1 - D(G(z)))]$$

DCGAN : Deep convolutional GAN

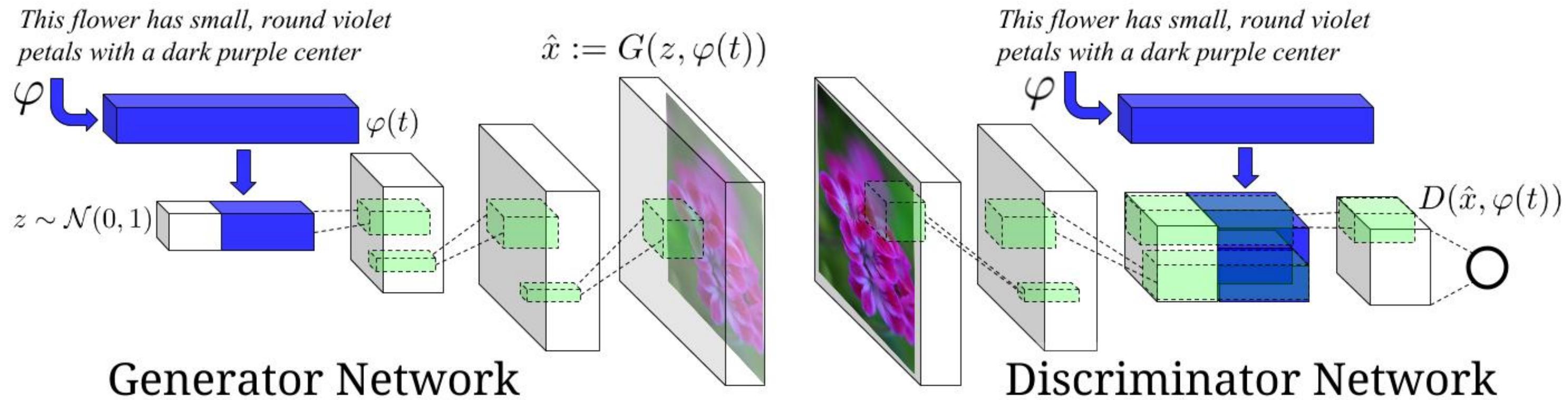
Generator



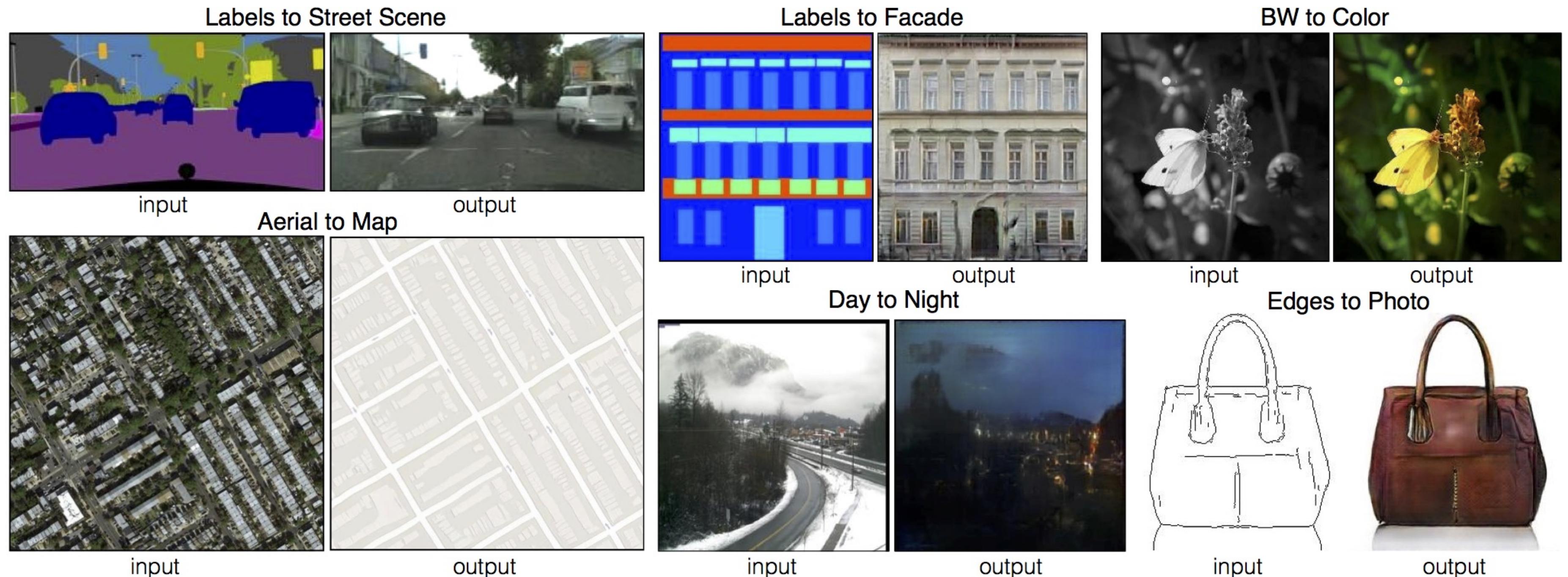
Discriminator



cGAN : conditional GAN for image synthesis

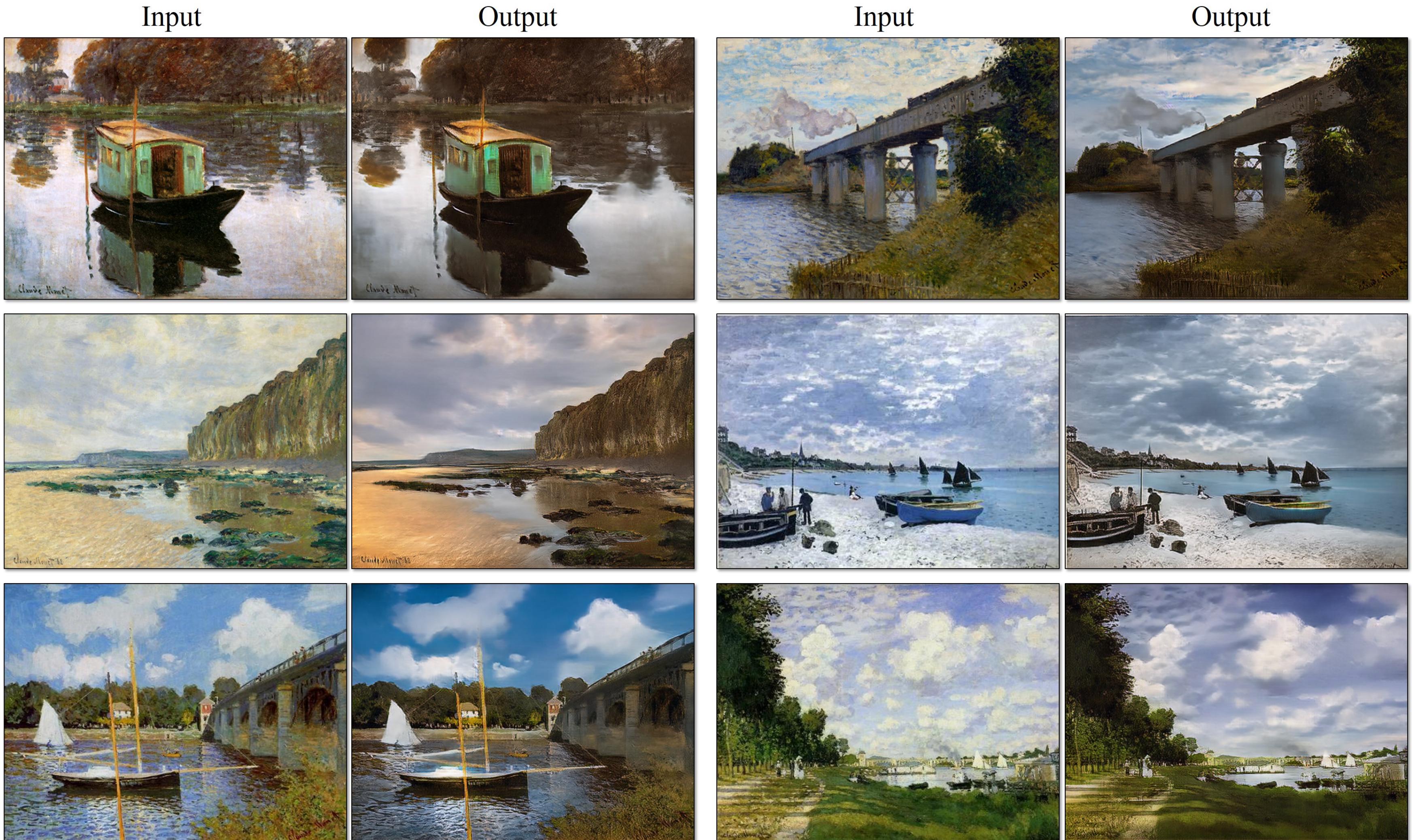


pix2pix : Image translation



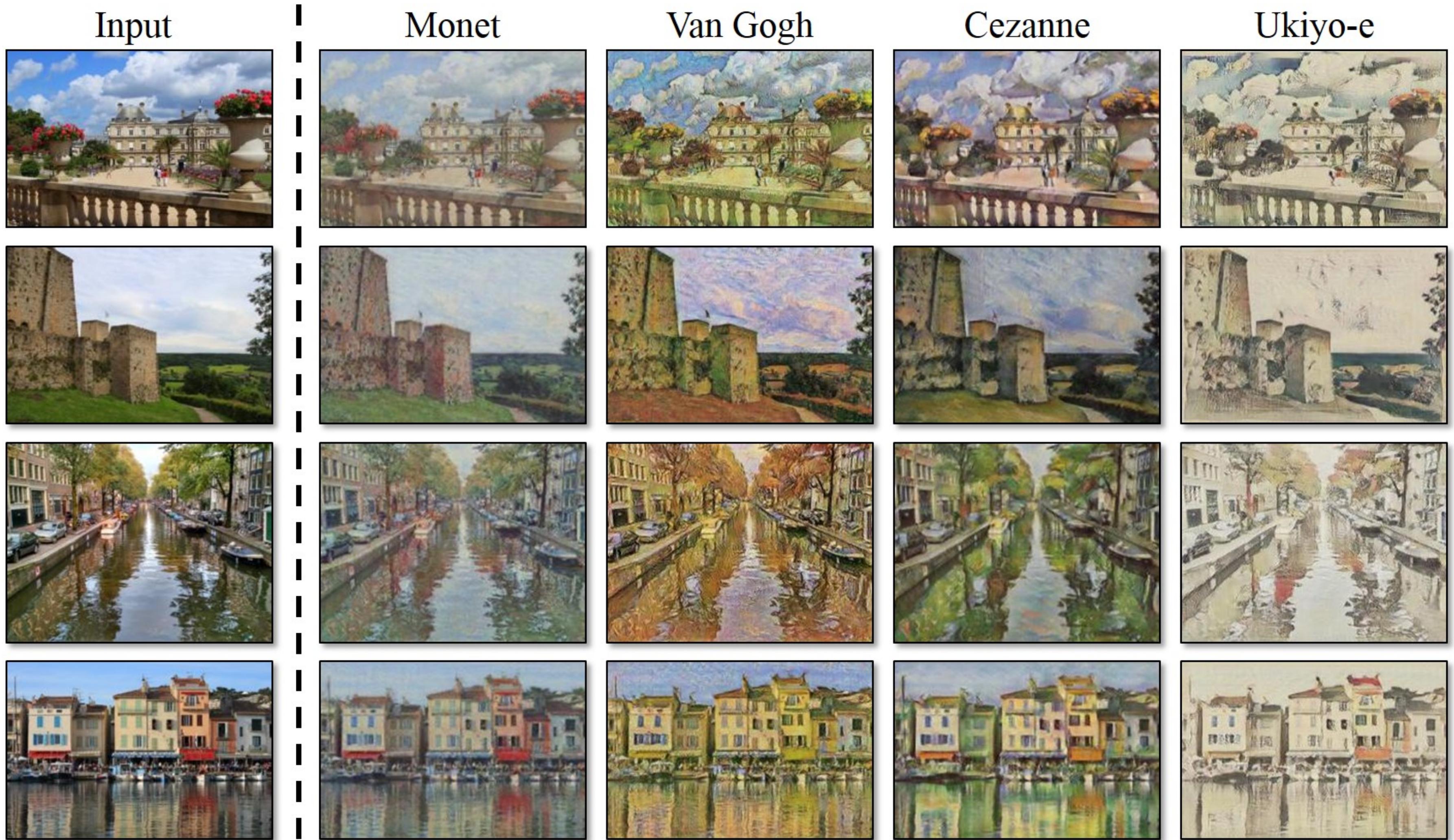
Source: <https://phillipi.github.io/pix2pix/>

CycleGAN : Monet Paintings to Photo



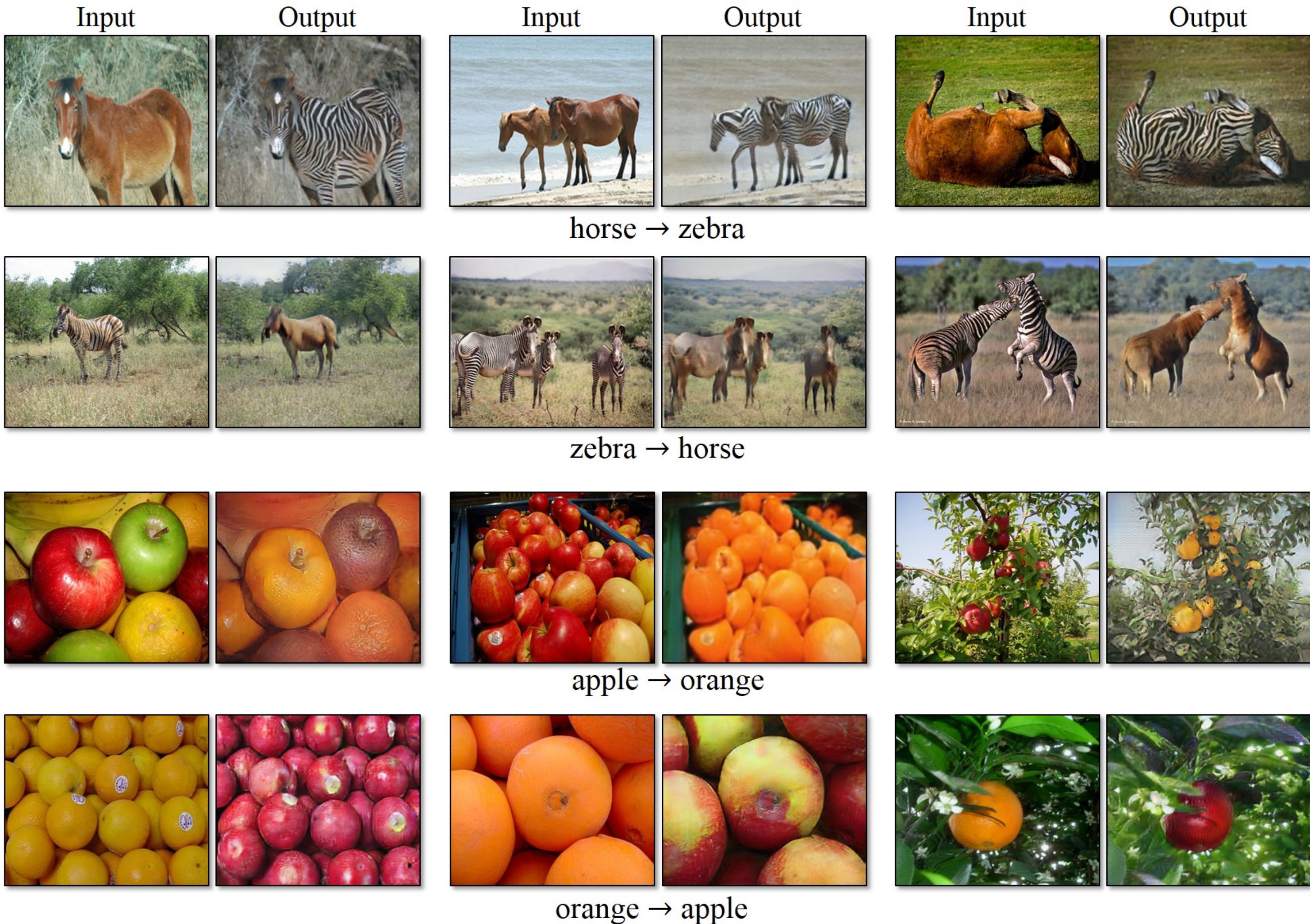
Source: <https://github.com/junyanz/CycleGAN>

CycleGAN : Neural Style Transfer



Source: <https://github.com/junyanz/CycleGAN>

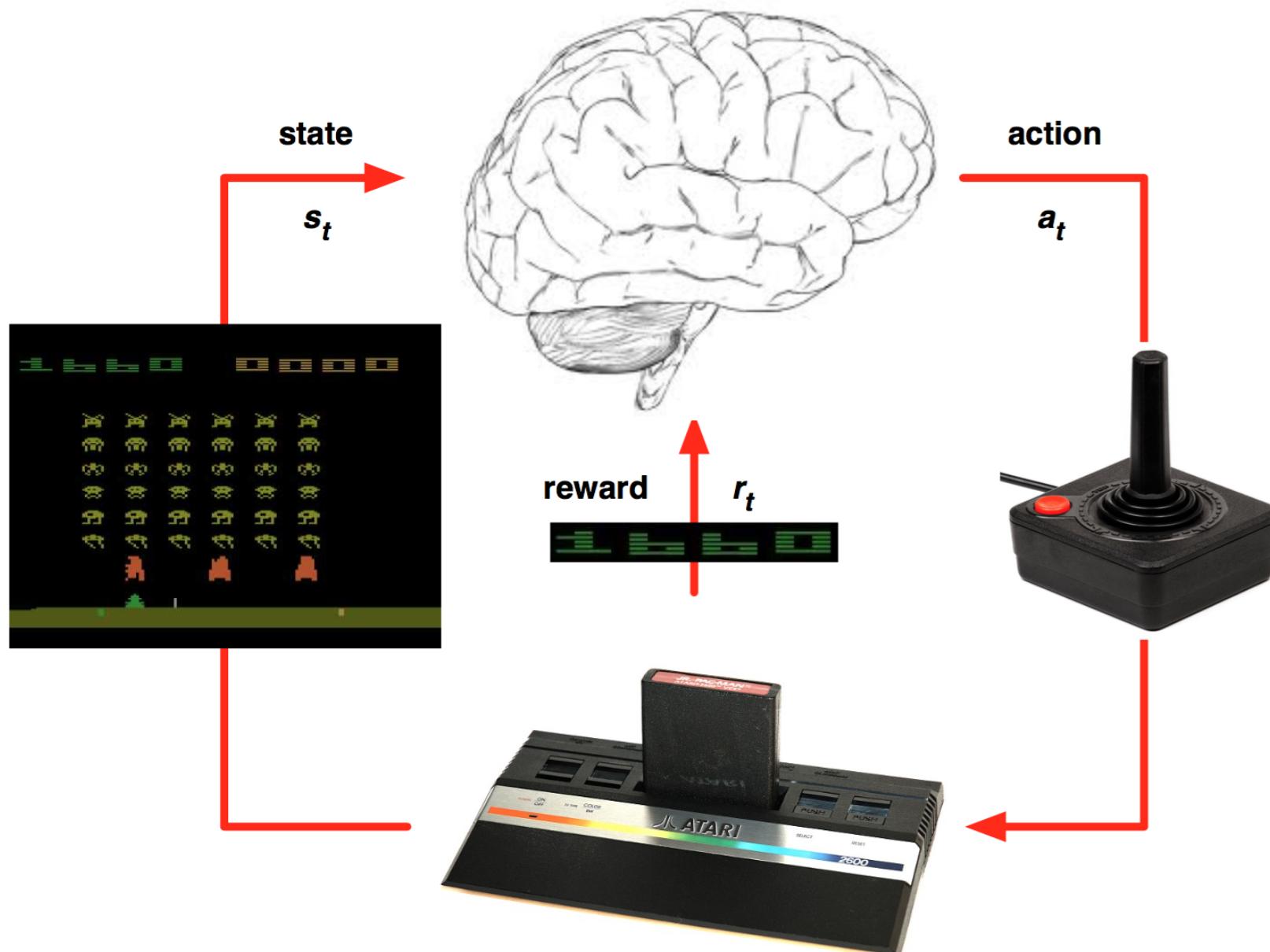
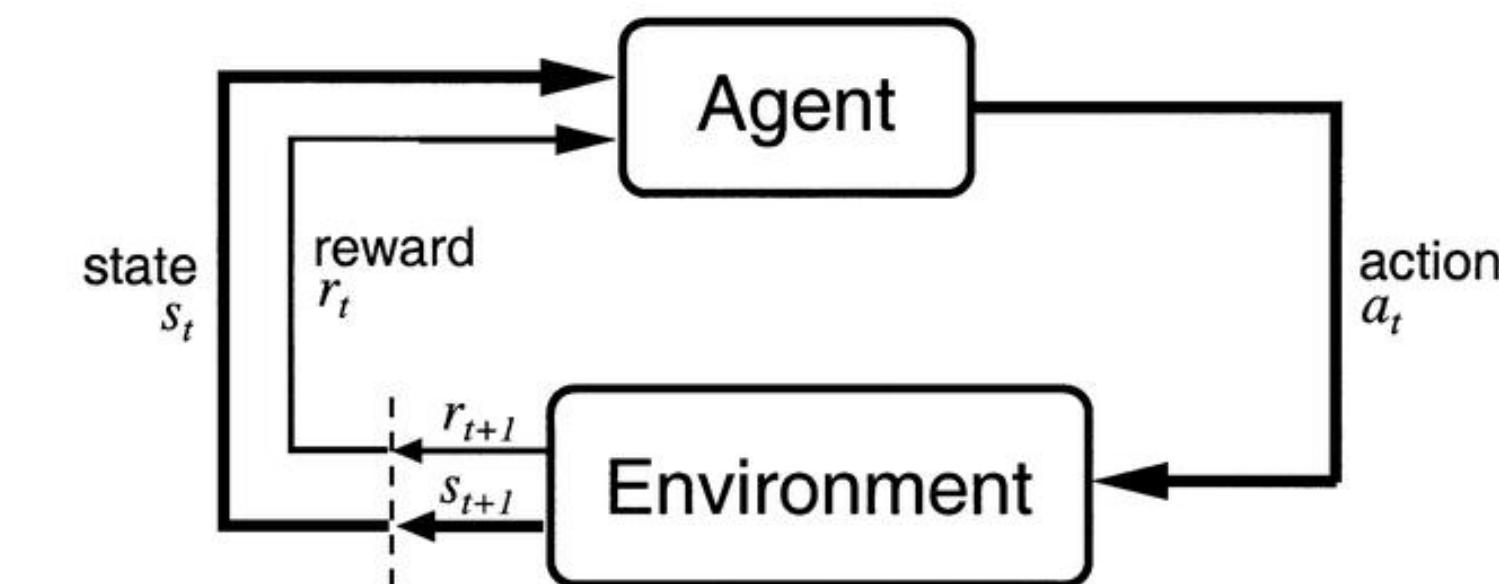
CycleGAN : Object Transfiguration



Source: <https://github.com/junyanz/CycleGAN>

3 - Deep Reinforcement Learning

Reinforcement learning



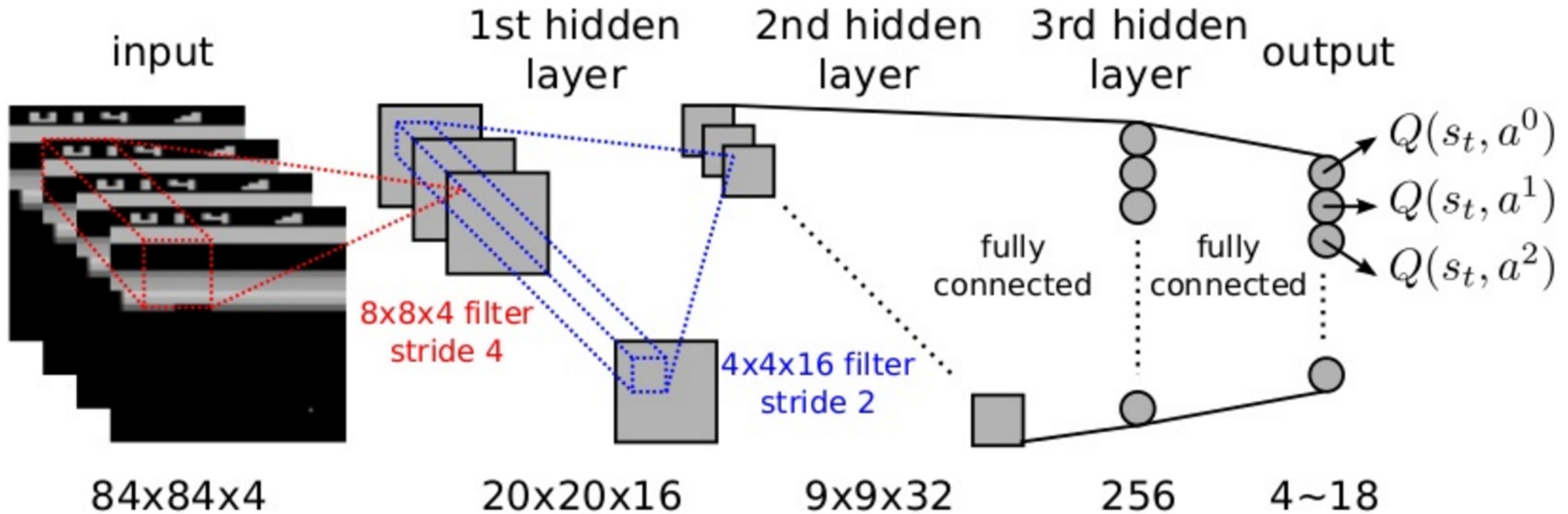
- **Supervised learning** allows to learn complex input/output mappings, given there is enough data.
- Sometimes we do not know the correct output, only whether the proposed output is correct or not (*partial feedback*).
- **Reinforcement Learning (RL)** can be used to learn by **trial and error** an optimal policy $\pi(s, a)$.
- Each action (=output) is associated to a **reward**.
- The goal of the system is to find a policy that maximizes the sum of the rewards on the **long-term** (return).

$$R(s_t, a_t) = \sum_{k=0}^{\infty} \gamma^k r_{t+k+1}$$

- See the deep reinforcement learning course:

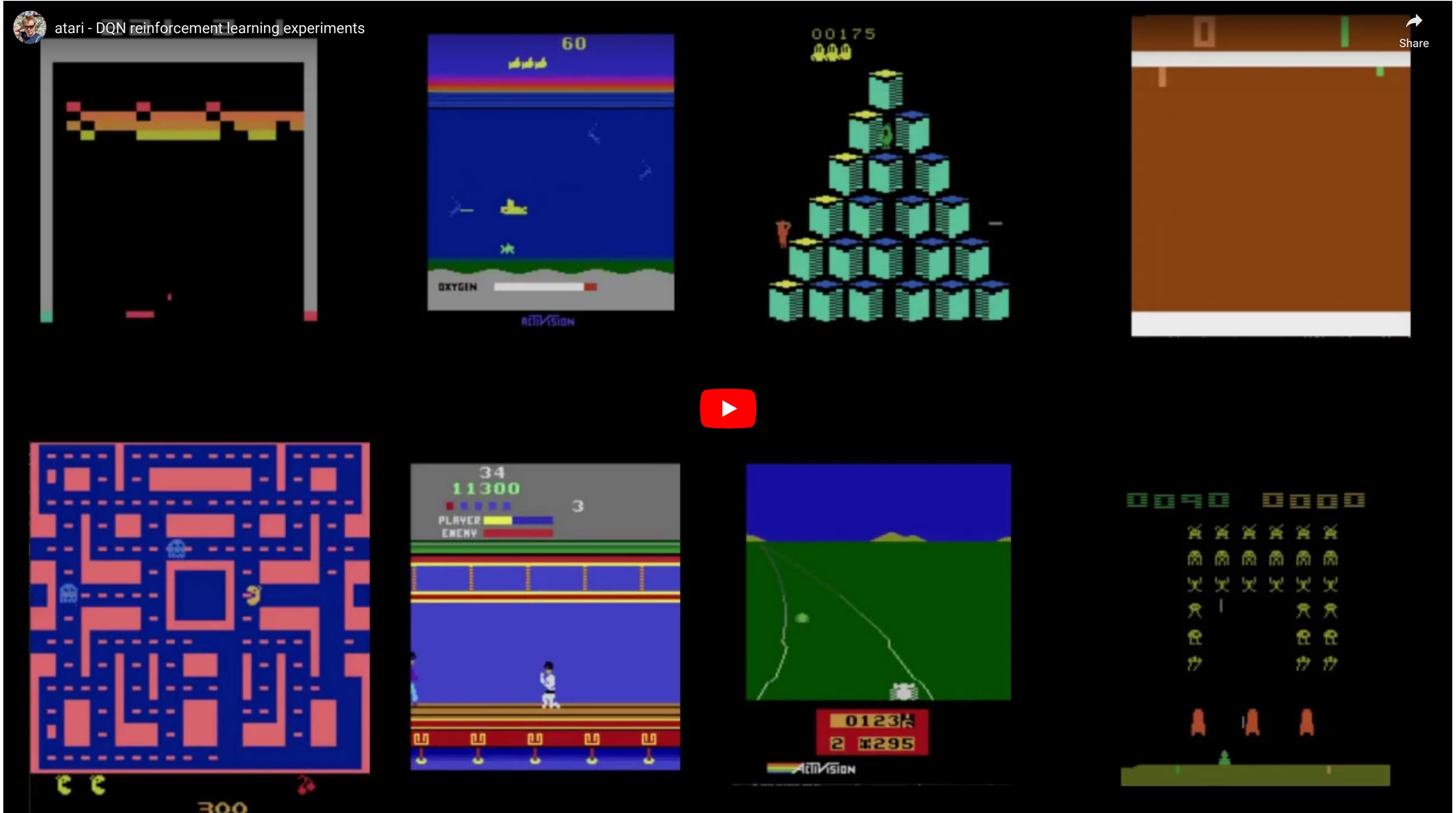
<https://www.tu-chemnitz.de/informatik/KI/edu/deeprl/>

DQN : learning to play Atari games

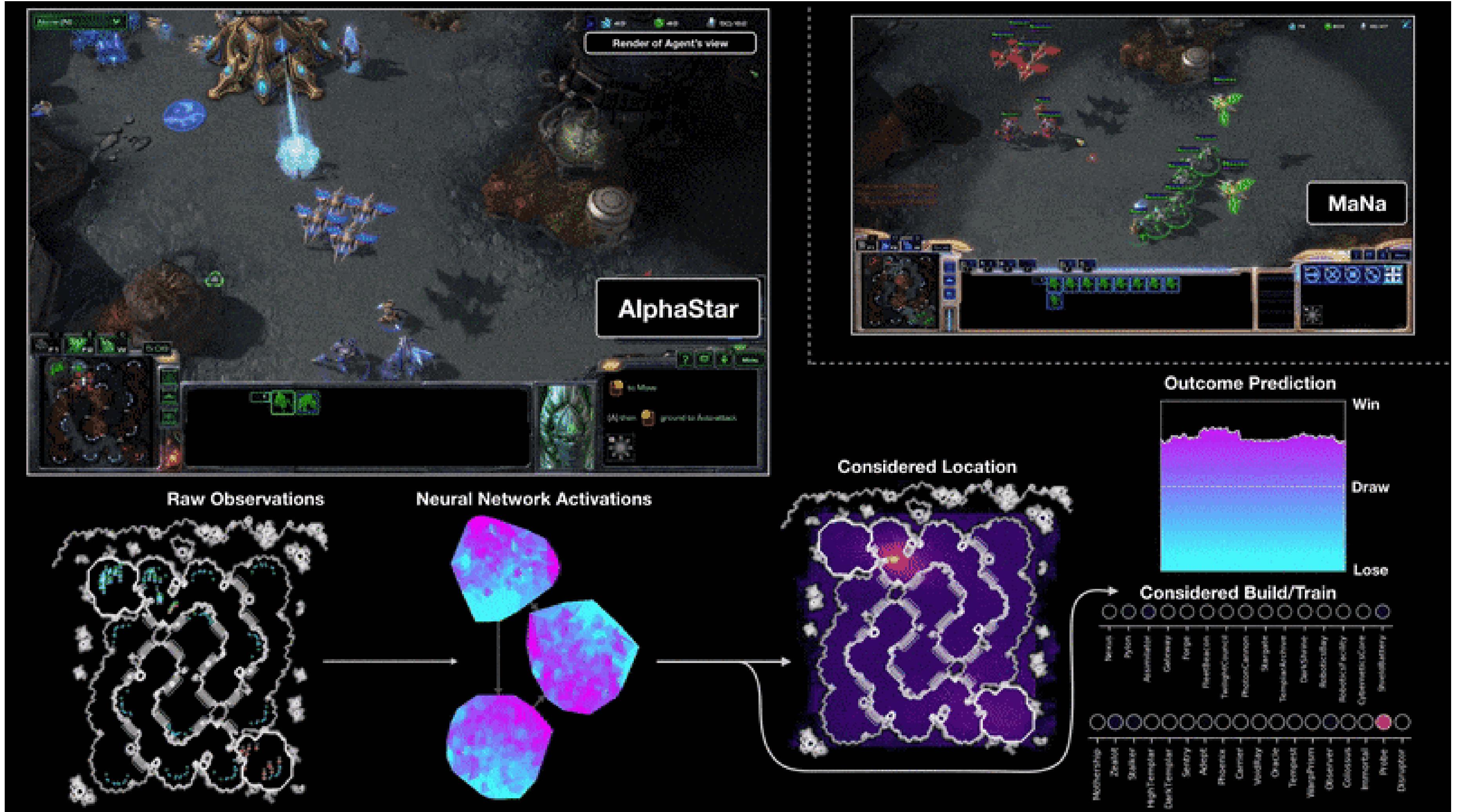


- A CNN takes raw images as inputs and outputs the probabilities of taking particular actions.
- Learning is only based on **trial and error**: what happens if I do that?
- The goal is simply to maximize the final score.

DQN : learning to play Atari games

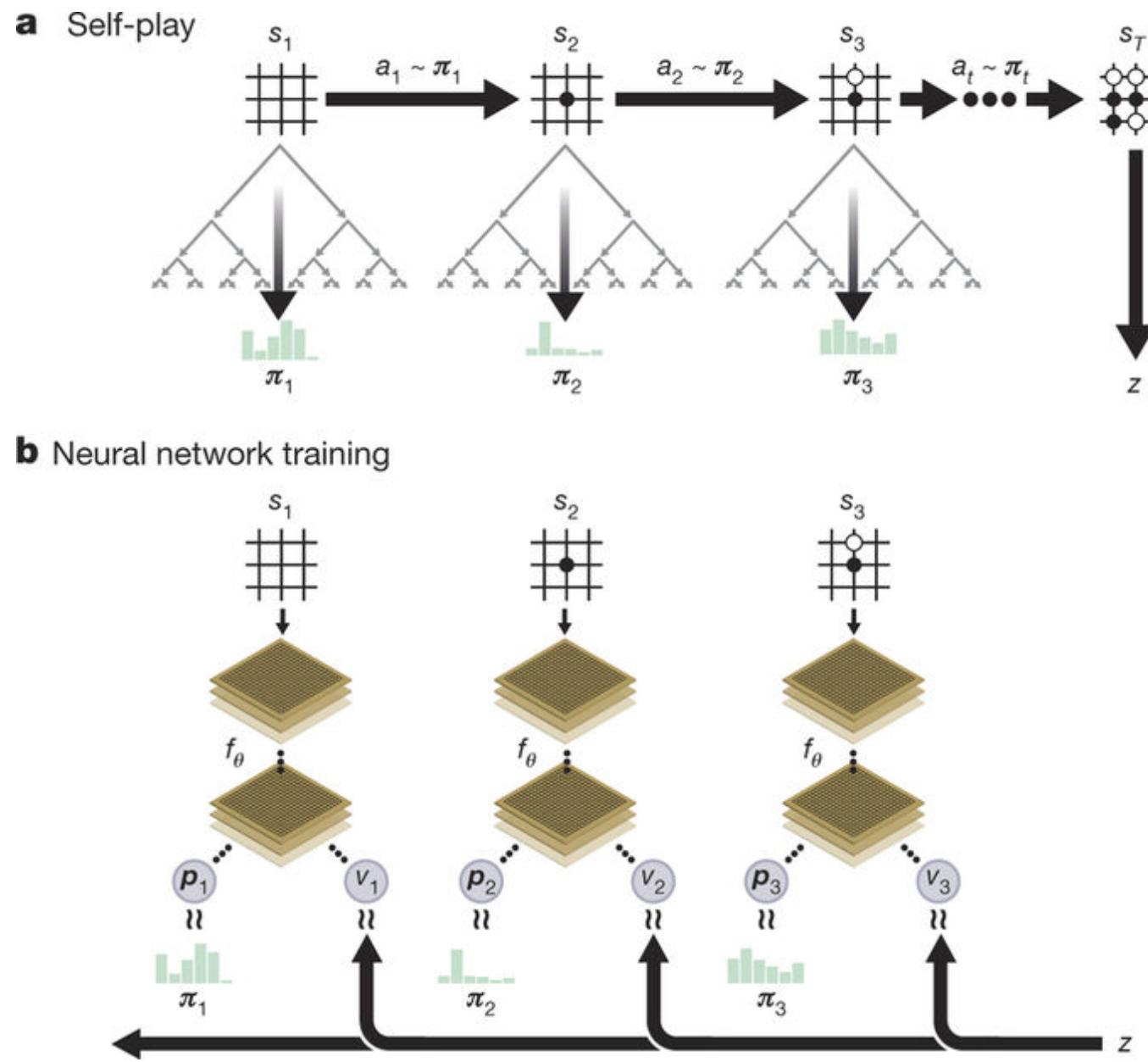


AlphaStar : learning to play Starcraft II



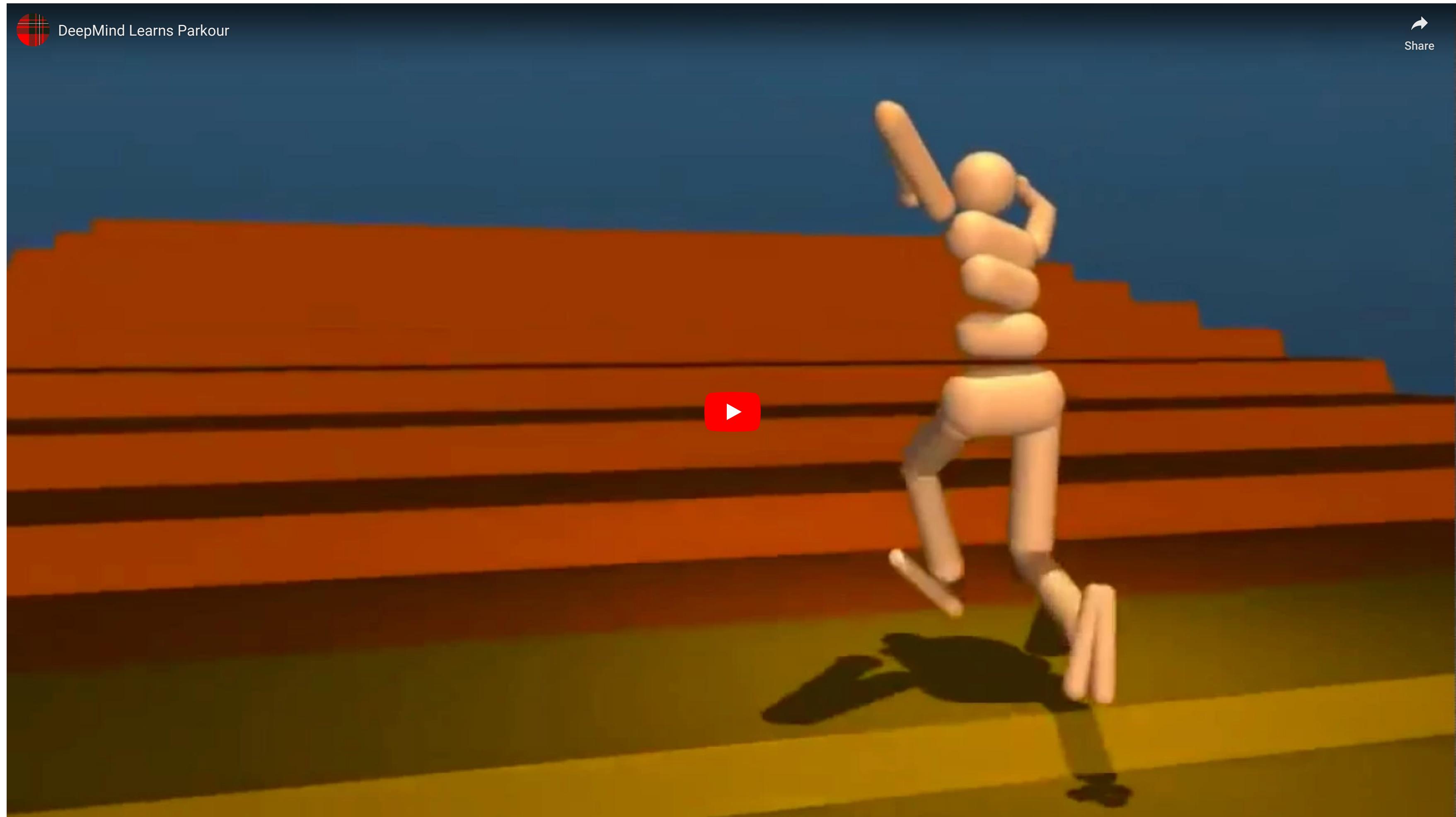
<https://deepmind.com/blog/alphastar-mastering-real-time-strategy-game-starcraft-ii/>

Google Deepmind - AlphaGo

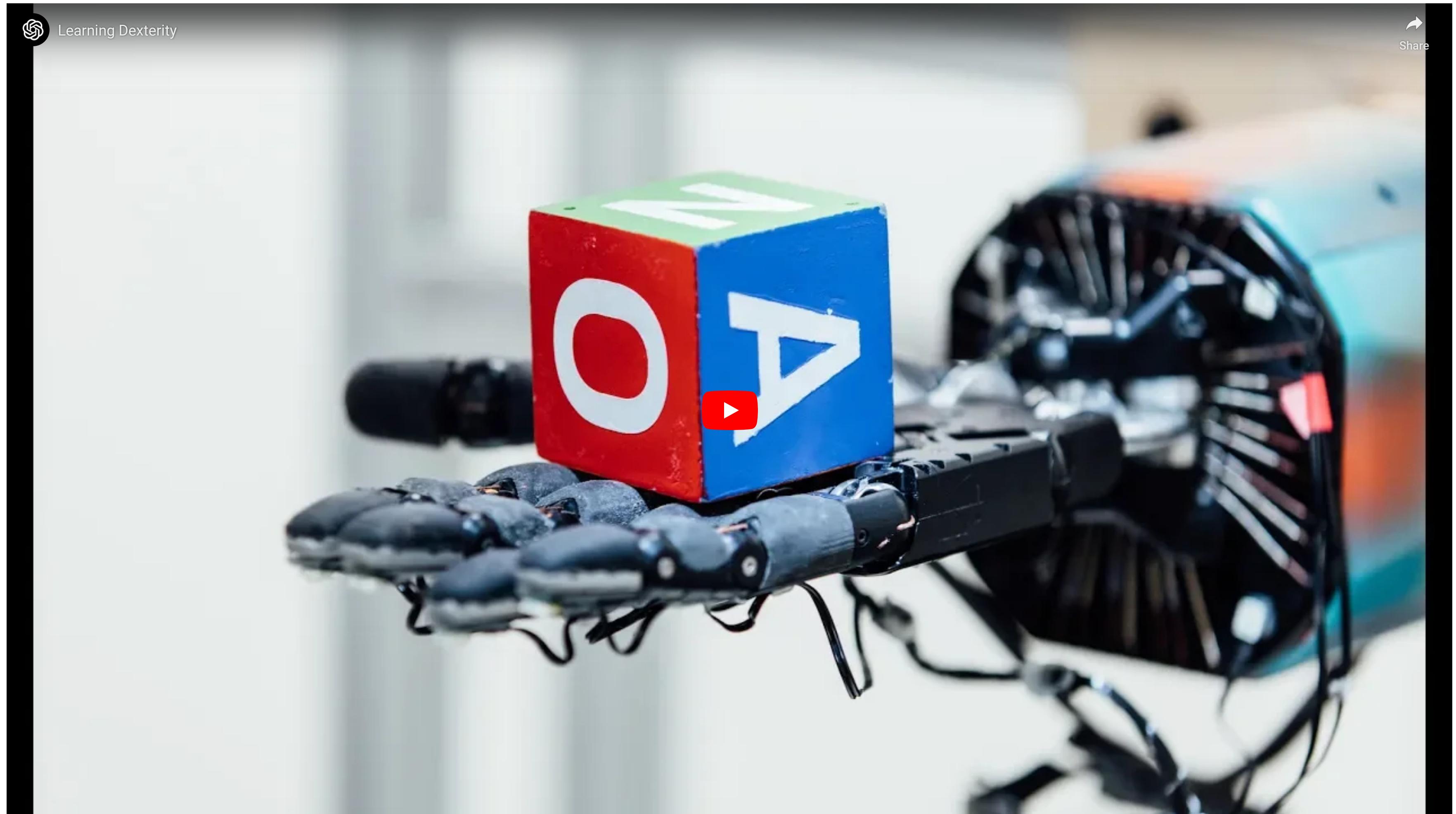


- In 2015, Google Deepmind surprised everyone by publishing **AlphaGo**, a Go AI able to beat the world's best players, including **Lee Sedol** in 2016, 19 times world champion.
- The RL agent discovers new strategies by using self-play: during the games against Lee Sedol, it was able to use **novel** moves which were never played before and surprised its opponent.
- The new version **AlphaZero** also plays chess and sokoban at the master level.

Parkour



Dexterity



Autonomous driving



Neurocomputing syllabus

1. Linear learning machines

- Optimization, Gradient Descent
- Linear regression and classification
- Multi-class classification
- Learning theory, Cross-validation

2. Neural networks

- Multi-layer perceptron
- Backpropagation algorithm
- Regularization, Batch Normalization

3. Convolutional neural networks

- Convolutional layer, pooling
- Transfer learning
- Object detection (Fast-RCNN, YOLO)
- Semantic segmentation

4. Autoencoders and generative models

- Auto-encoders
- Variational autoencoders
- Restricted Boltzmann machines
- Generative adversarial networks

5. Recurrent Neural Networks

- RNN
- LSTM / GRU
- Attention-gated networks

6. Self-supervised learning

- Transformers
- Contrastive learning

7. Outlook

Literature

- **Deep Learning.** *Ian Goodfellow, Yoshua Bengio & Aaron Courville*, MIT press.

<http://www.deeplearningbook.org>

- **Neural Networks and Learning Machines.** *Simon Haykin*, Pearson International Edition.

<http://www.pearsonhighered.com/haykin>

- **Deep Learning with Python.** *Francois Chollet*, Manning.

<https://www.manning.com/books/deep-learning-with-python>

- **The Elements of Statistical Learning: Data Mining, Inference, and Prediction,** *Trevor Hastie, Robert Tibshirani & Jerome Friedman*, Springer.

https://web.stanford.edu/~hastie/ElemStatLearn/printings/ESLII_print12.pdf

But also

- The machine learning course of Andrew Ng (Stanford at the time) hosted on Coursera is great for beginners:

<https://www.coursera.org/learn/machine-learning>

- His advanced course on deep learning allows to go further:

<https://www.coursera.org/specializations/deep-learning>

- The machine learning course on EdX focuses on classical ML methods and is a good complement to this course:

<https://www.edx.org/course/machine-learning>

- <https://medium.com> has a lot of excellent blog posts explaining AI-related topics, especially:

<https://towardsdatascience.com/>

- The d2l.ai online book is a great resource, including programming exercises:

<http://d2l.ai/index.html>