DOMINO

Practical Deep Learning for Data Scientists Tutorial

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AGENDA

- Introduction
- Deep Learning in Practice
- Evaluating Models
- Optimizing Models
- Summary

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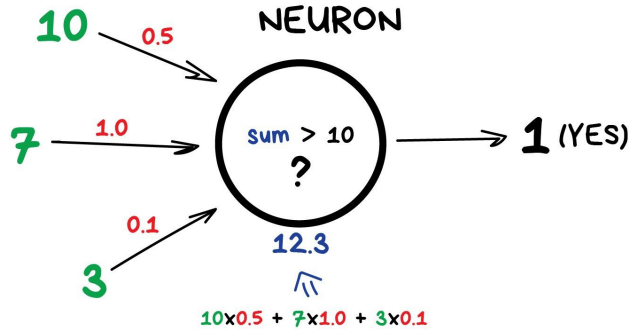
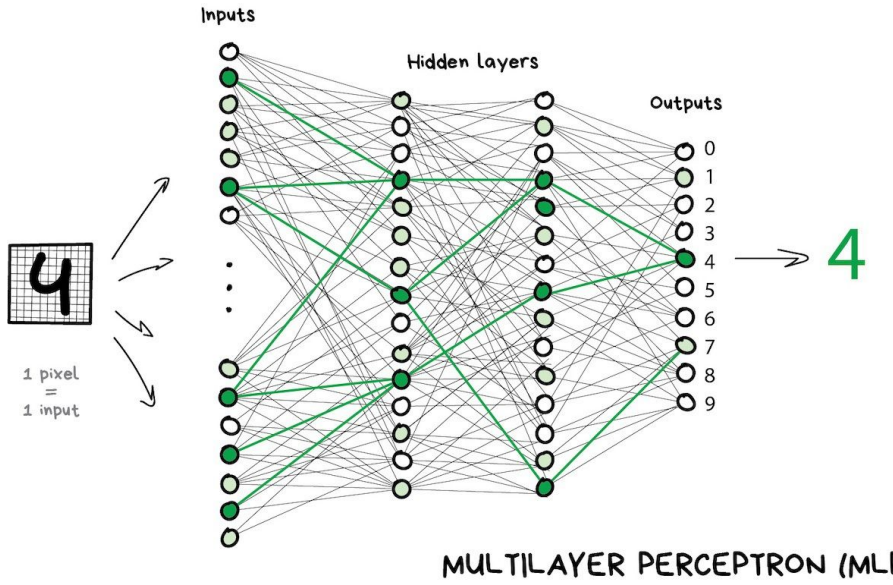
Introduction

WHAT IS DEEP LEARNING?

Deep Learning is a type of machine learning inspired by the structure of the brain

- Algorithm perform a task numerous times, via a system of weighted connections, making improvements each time
- Referred to as ‘deep’ learning because inputs are processed via deep layers that enable learning





https://vas3k.com/blog/machine_learning/

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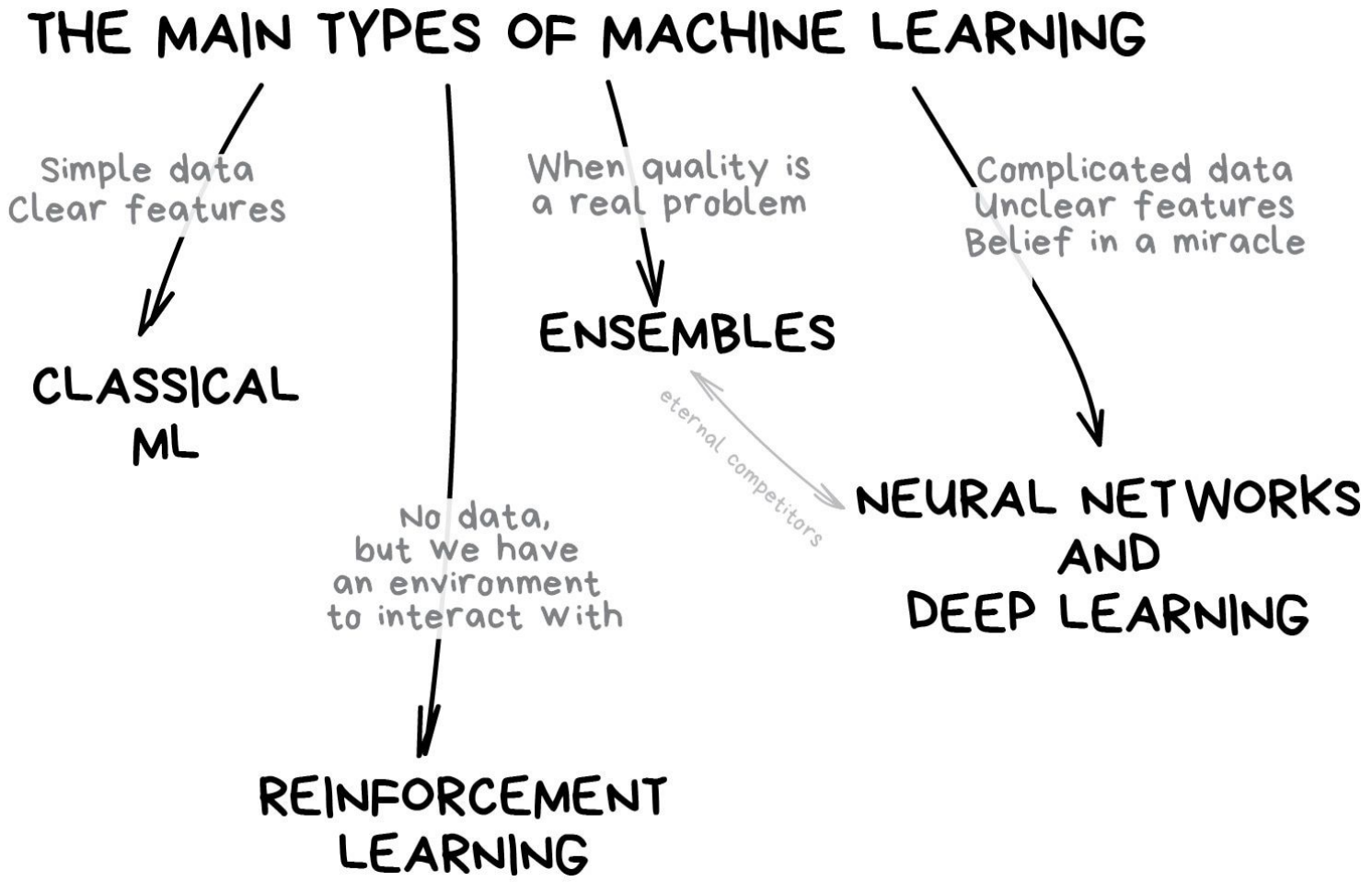
THE MACHINE LEARNING LANDSCAPE



https://vas3k.com/blog/machine_learning/

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WHEN TO USE DEEP LEARNING

- Complex tasks
- Unstructured but large amount of data
- You do not need a highly interpretable model
- You have the time and/or resources to train a model

DEEP LEARNING EXAMPLES

Object Identification and Facial Recognition

Speech Recognition - Virtual Assistants, apps for identifying songs

Deep Fakes

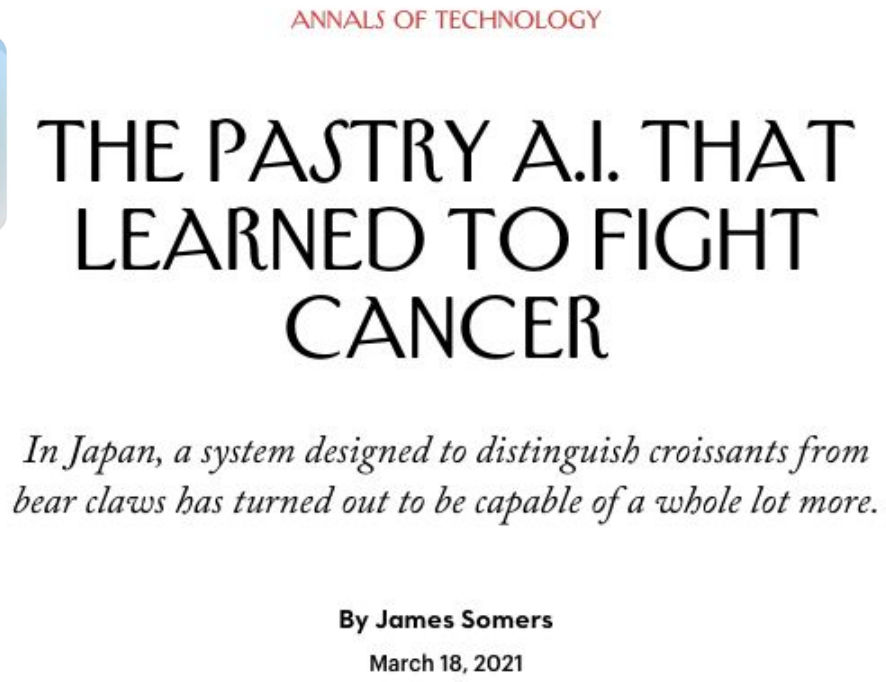
Self-Driving Vehicles

Personalized Entertainment

DEEP LEARNING EXAMPLES - OBJECT RECOGNITION

Developed algorithm to speed up checkout at bakeries

A doctor saw a segment about the BakeryScan and realized that cancer cells, under a microscope, looked kind of like bread


ANNALS OF TECHNOLOGY

THE PASTRY A.I. THAT LEARNED TO FIGHT CANCER

In Japan, a system designed to distinguish croissants from bear claws has turned out to be capable of a whole lot more.

By James Somers

March 18, 2021

https://www.newyorker.com/tech/annals-of-technology/the-pastry-ai-that-learned-to-fight-cancer

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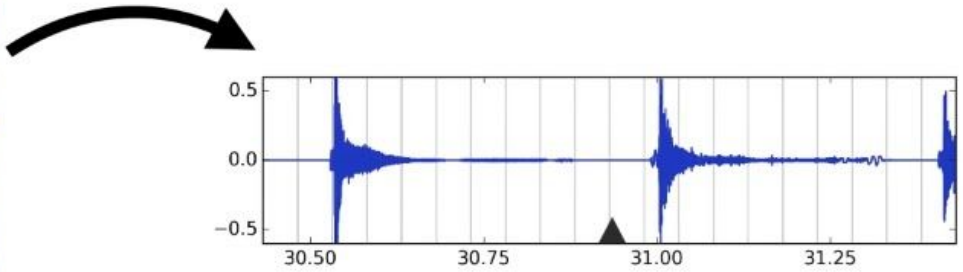
DEEP LEARNING EXAMPLES - PRODUCING SOUND

MIT researchers developed an algorithm that can produce a sound for a silent video that is realistic enough to fool human viewers

Data consisted of 1,000 videos of an estimated 46,000 sounds

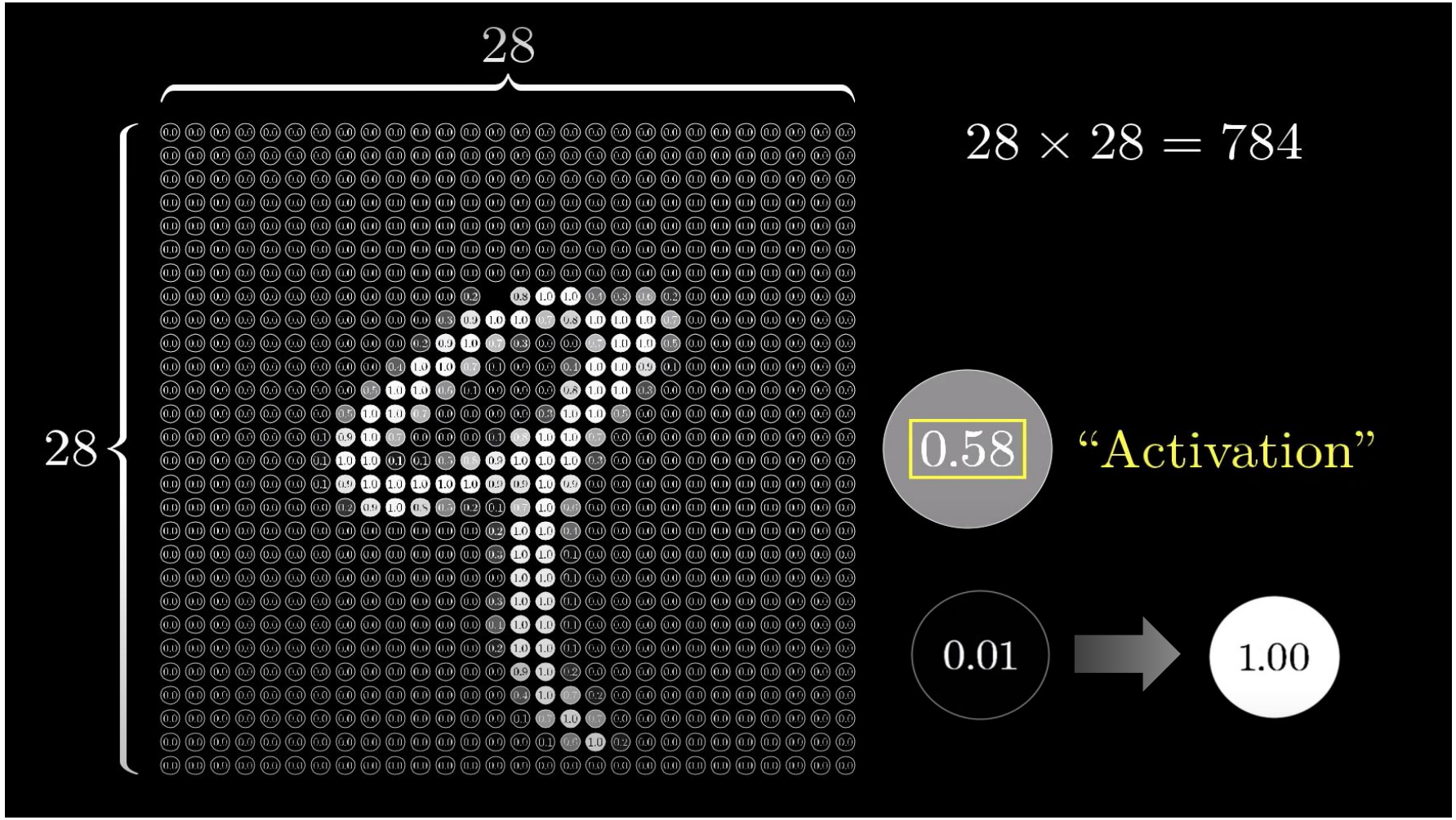
Silent video



Predicted soundtrack

https://news.mit.edu/2016/artificial-intelligence-produces-realistic-sounds-0613

WHAT IS A NEURAL NETWORK?



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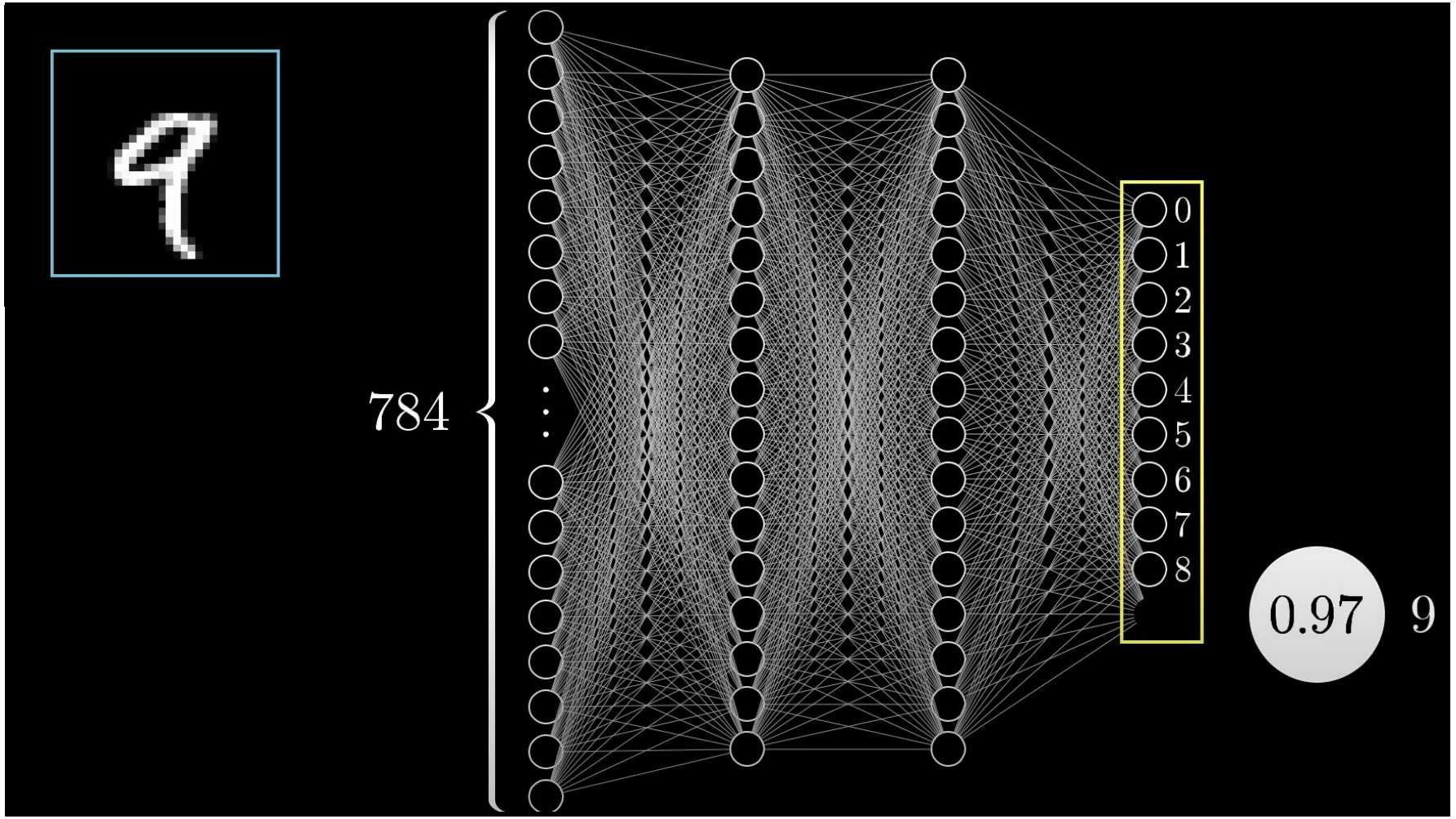
WHAT IS A NEURAL NETWORK?



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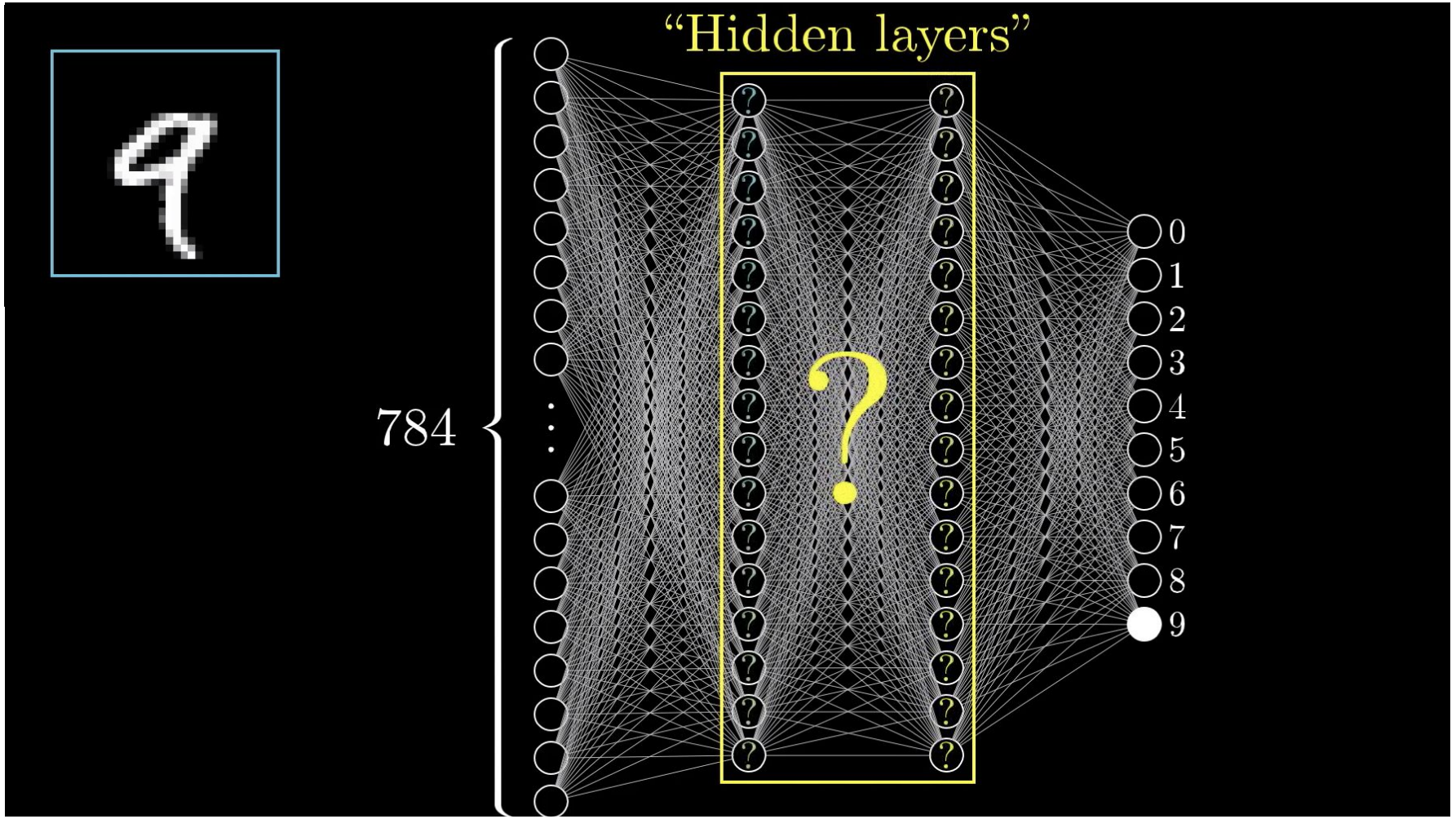

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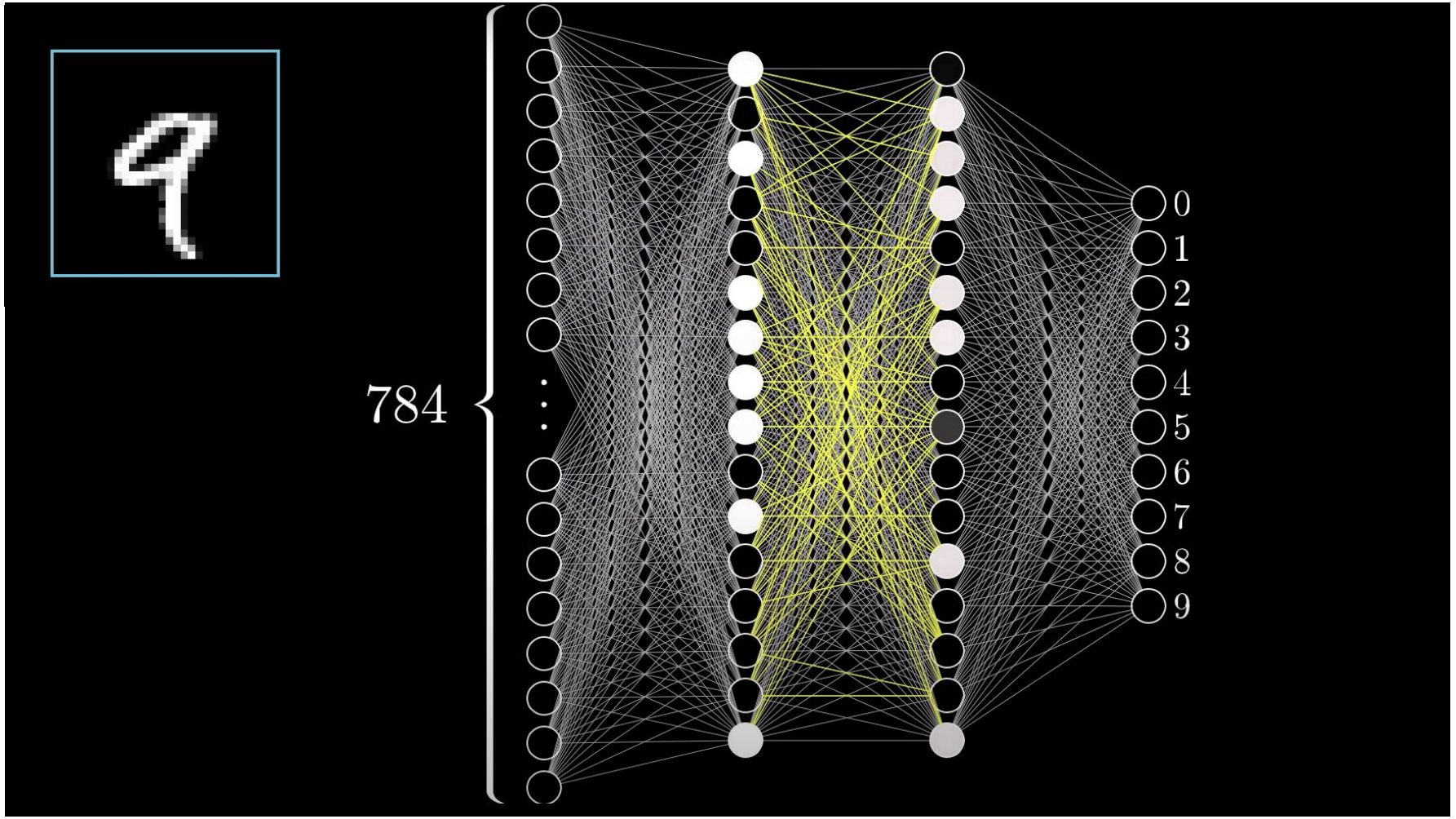

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WHAT IS A NEURAL NETWORK?

- The middle layers *ideally* represent subcomponents of the input
- In this example:
  - 2nd hidden layer = lines or loops that make up a digit
  - 1st hidden layer = edges that make up subcomponents of digits

- The final layer can then link to the combination of subcomponents that equal each digit

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WHAT IS A NEURAL NETWORK?

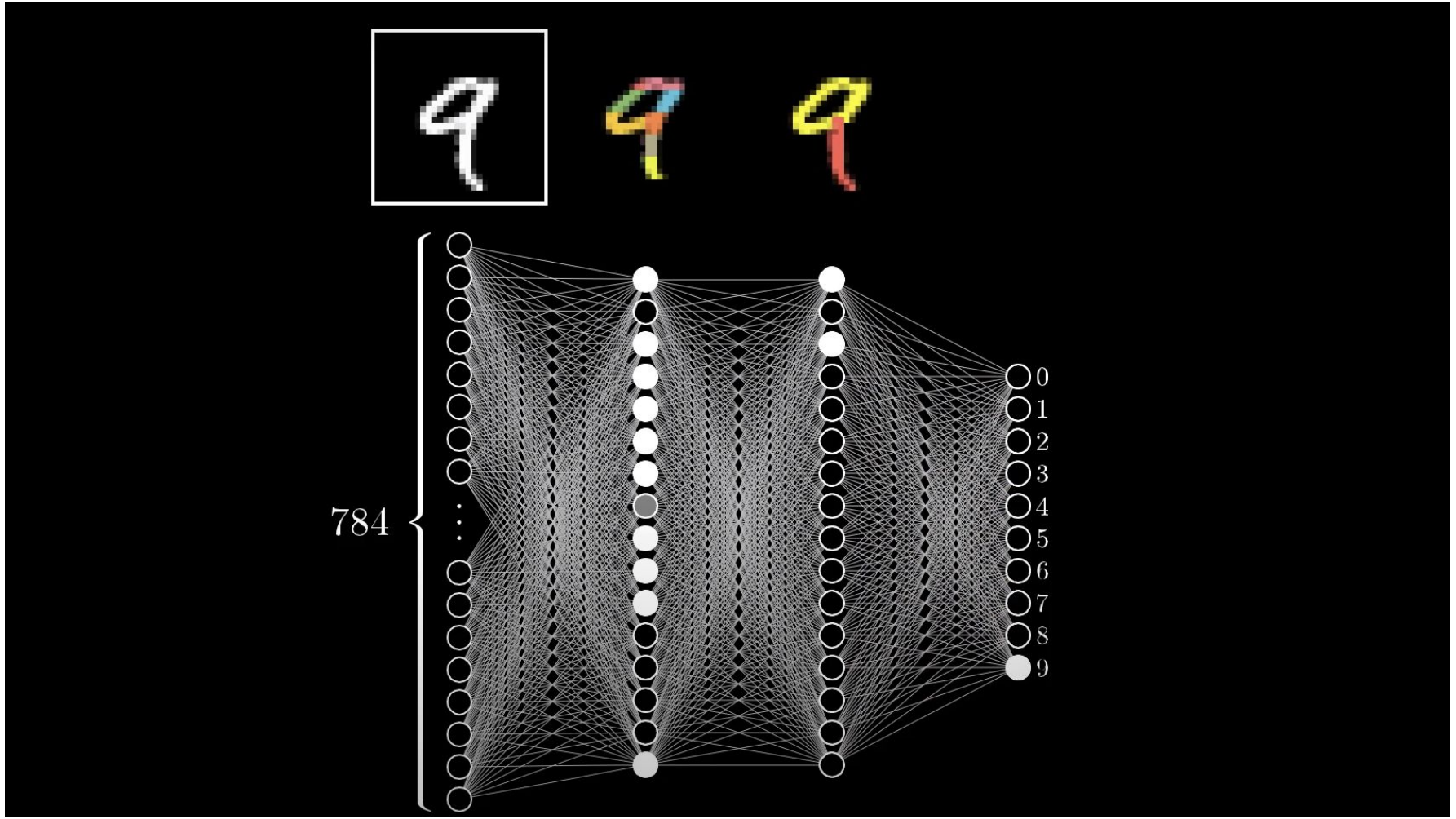

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IMAGE RECOGNITION

https://www.3blue1brown.com/

SPEECH RECOGNITION

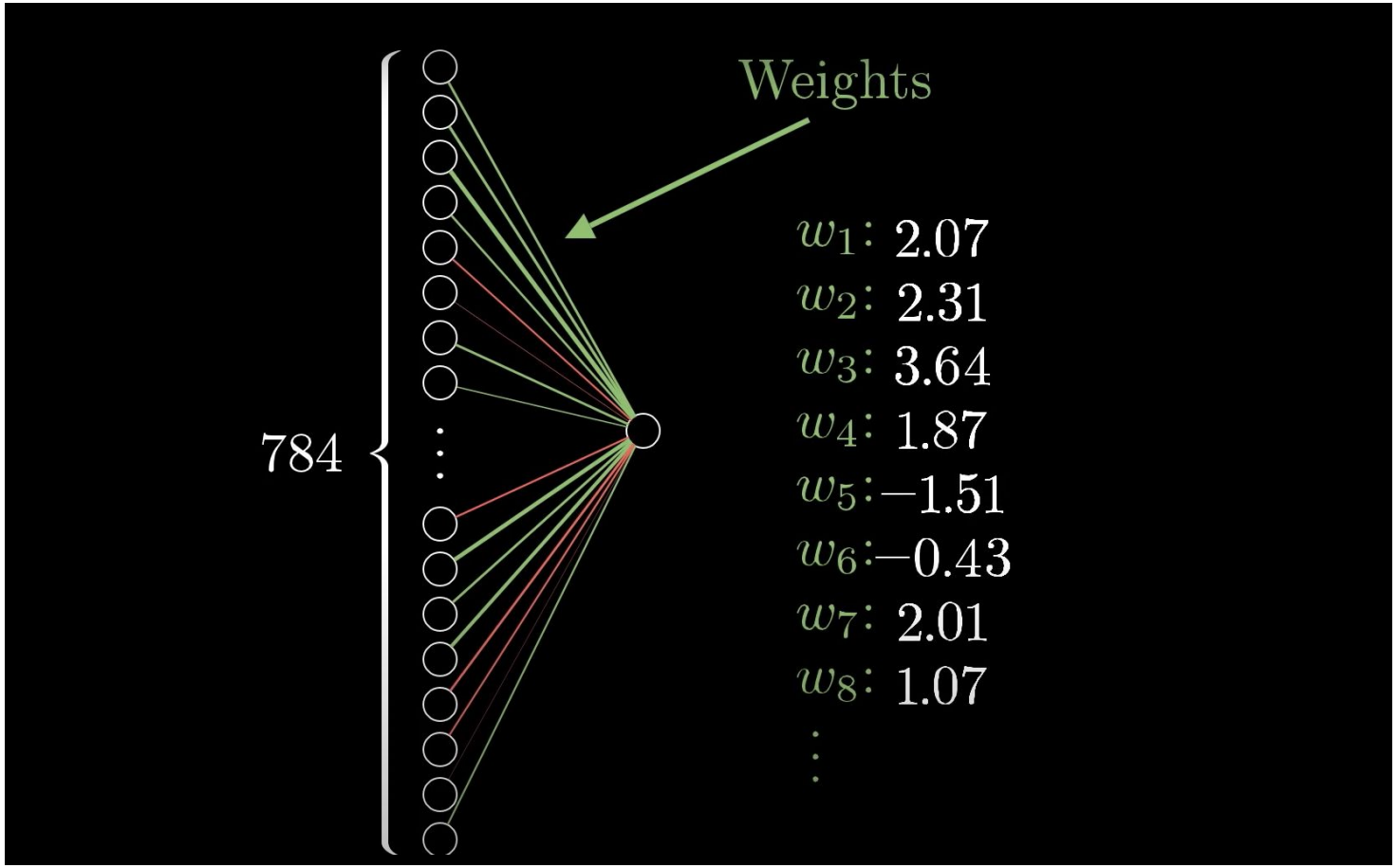
Parse raw audio → Break into distinct sounds →

Form syllables → Combine into words →

Phrases → etc

NEURAL NETWORK WEIGHTS

How can we ensure the hidden layers are capturing the desired patterns?



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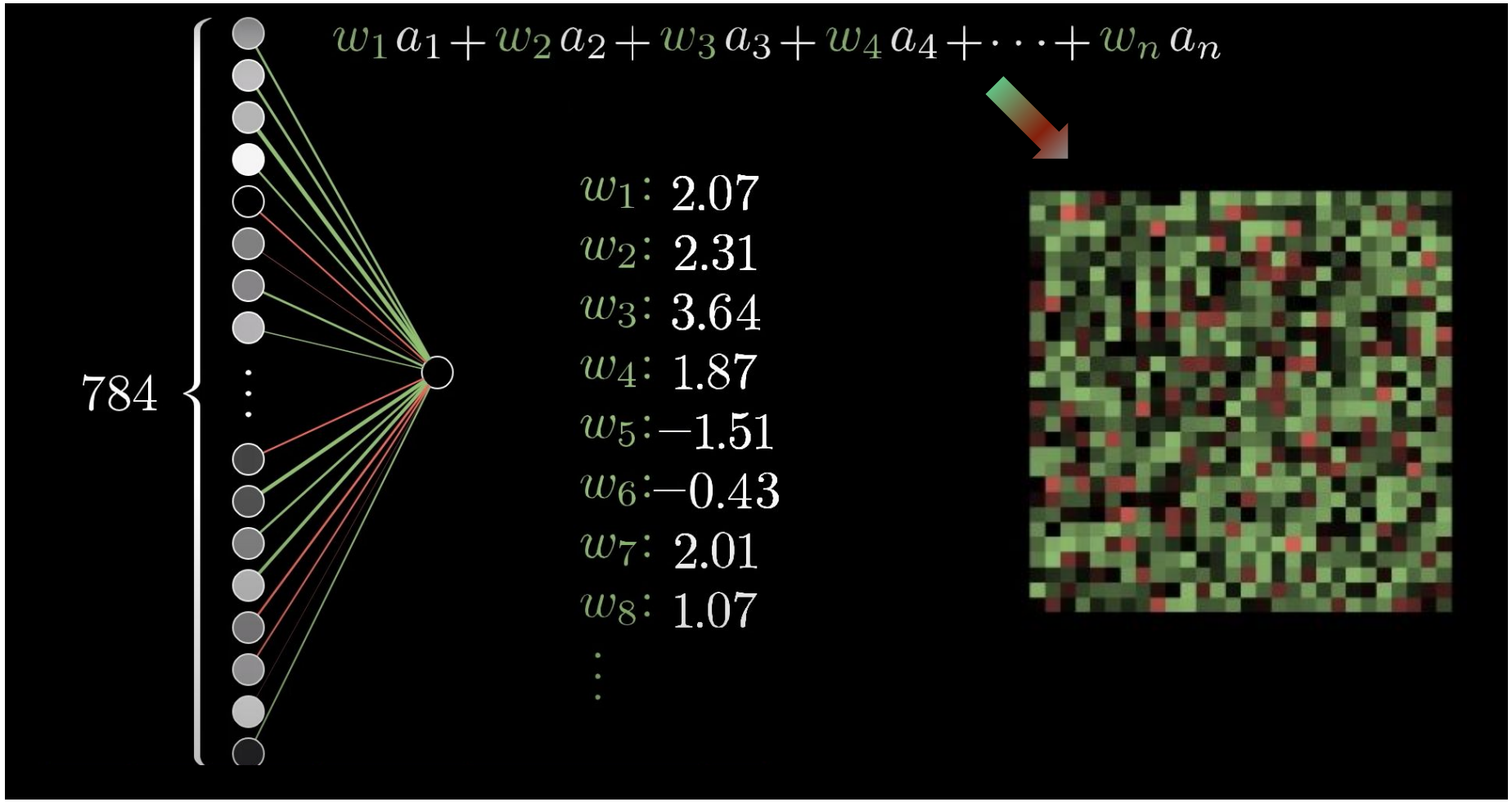
NEURAL NETWORK WEIGHTS



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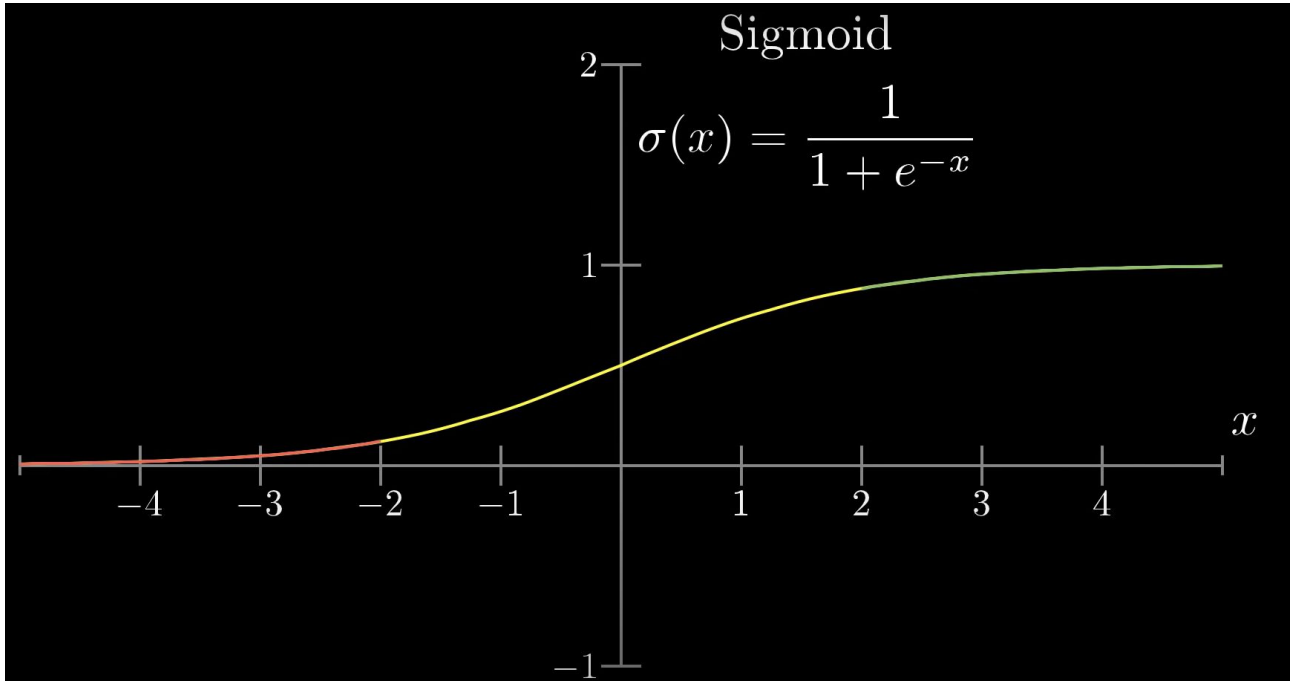
NEURAL NETWORK WEIGHTS

Each of those sums could be any number

To ensure we get an activation between 0 and 1 for the next layer we put those sums through a function

This is a sigmoid function, where very negative numbers are close to zero and very positive close to 1



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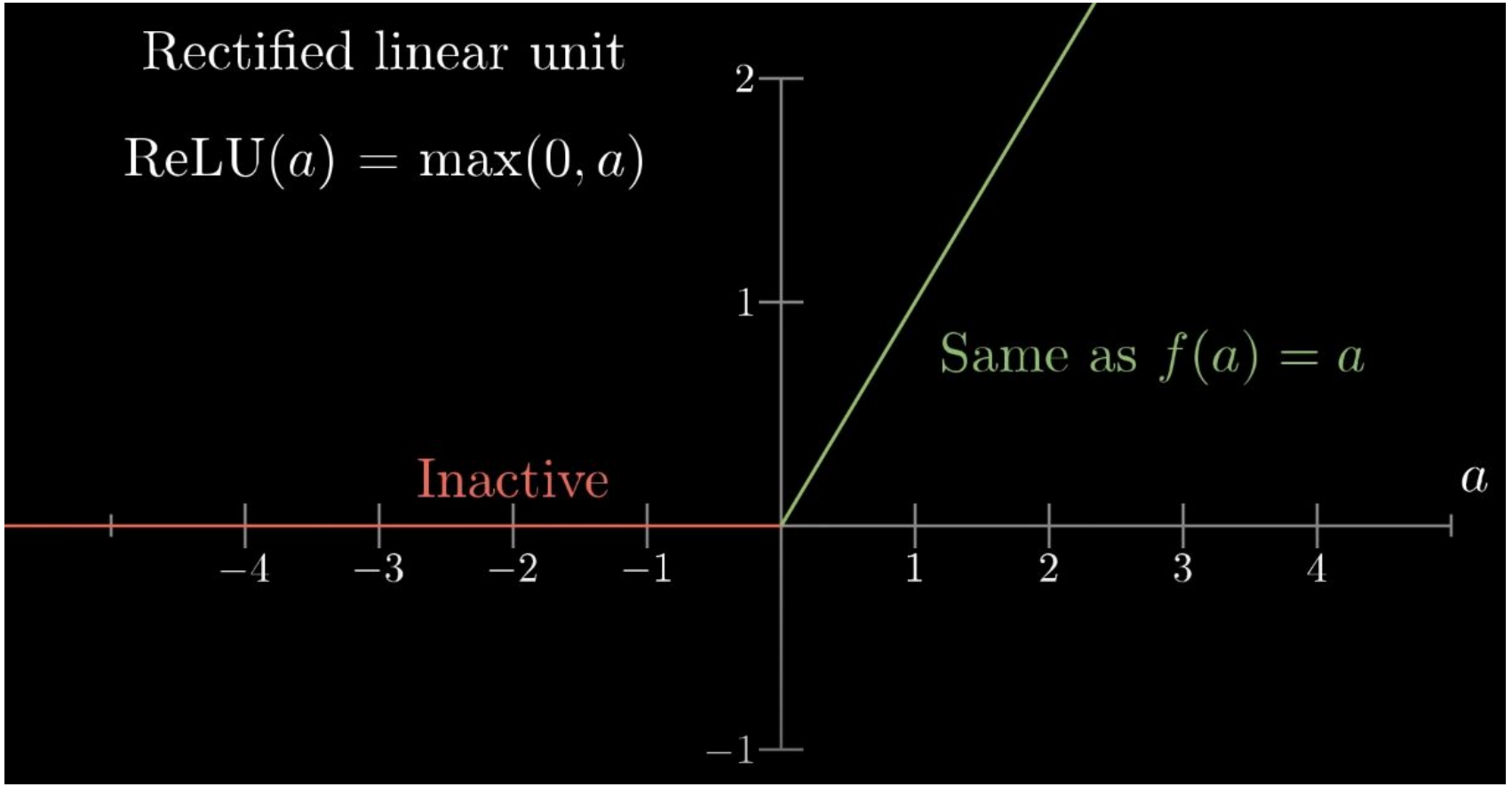
NEURAL NETWORK WEIGHTS



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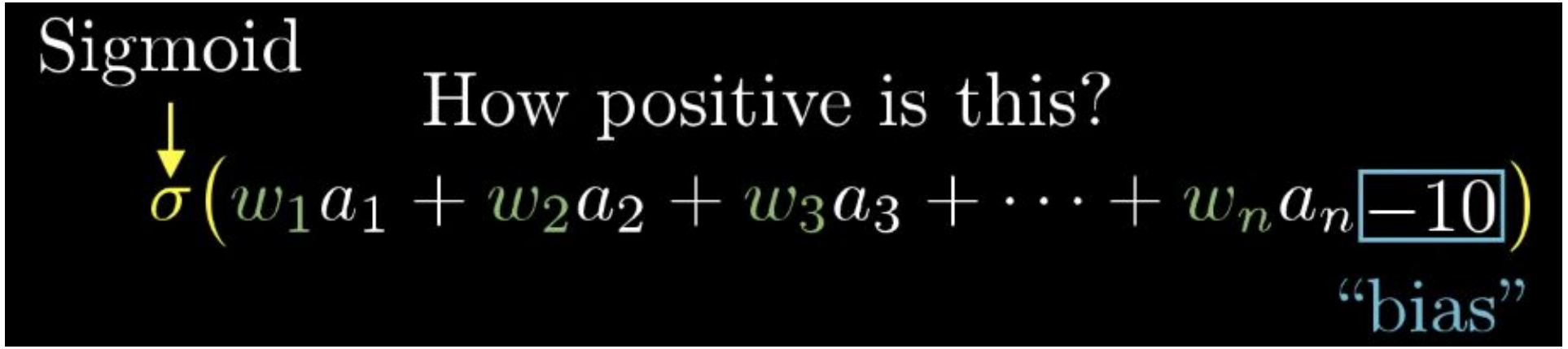
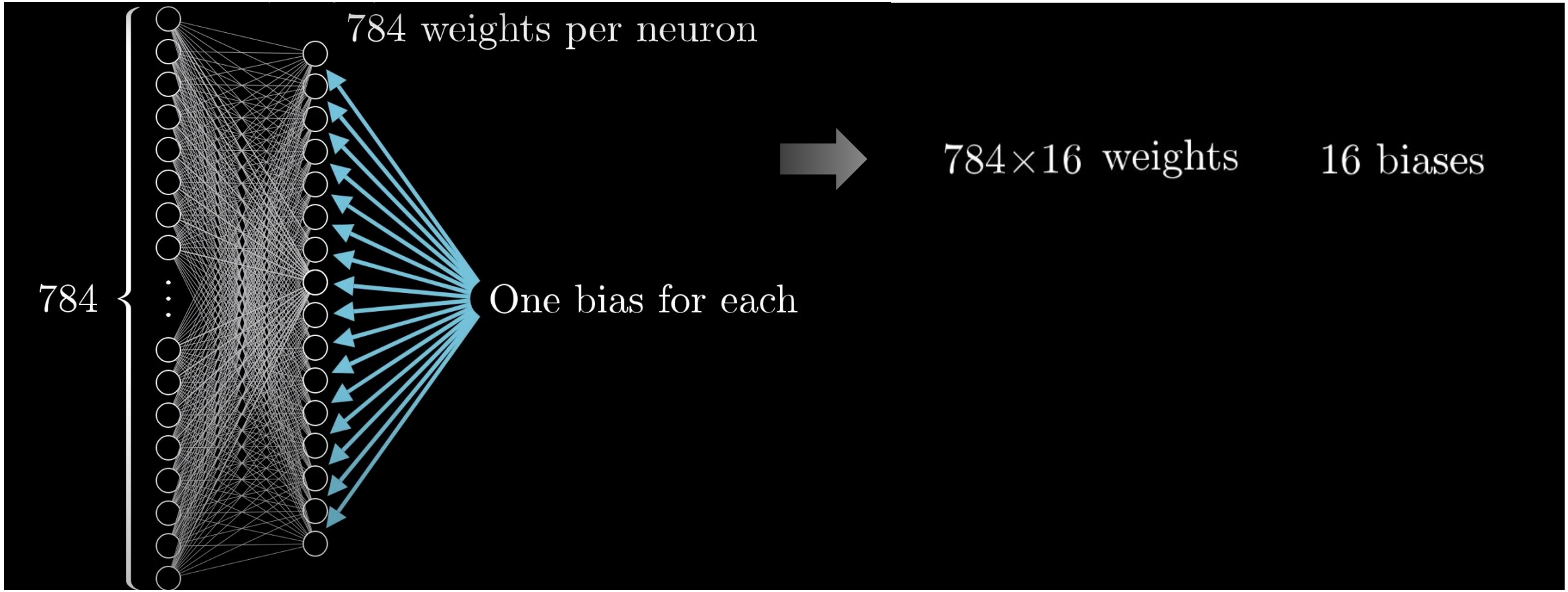
NEURAL NETWORK BIAS

We don’t necessarily want a neuron to light up when the activation sum is greater than 0, instead we may prefer a different threshold



https://www.3blue1brown.com/

NEURAL NETWORK LEARNING



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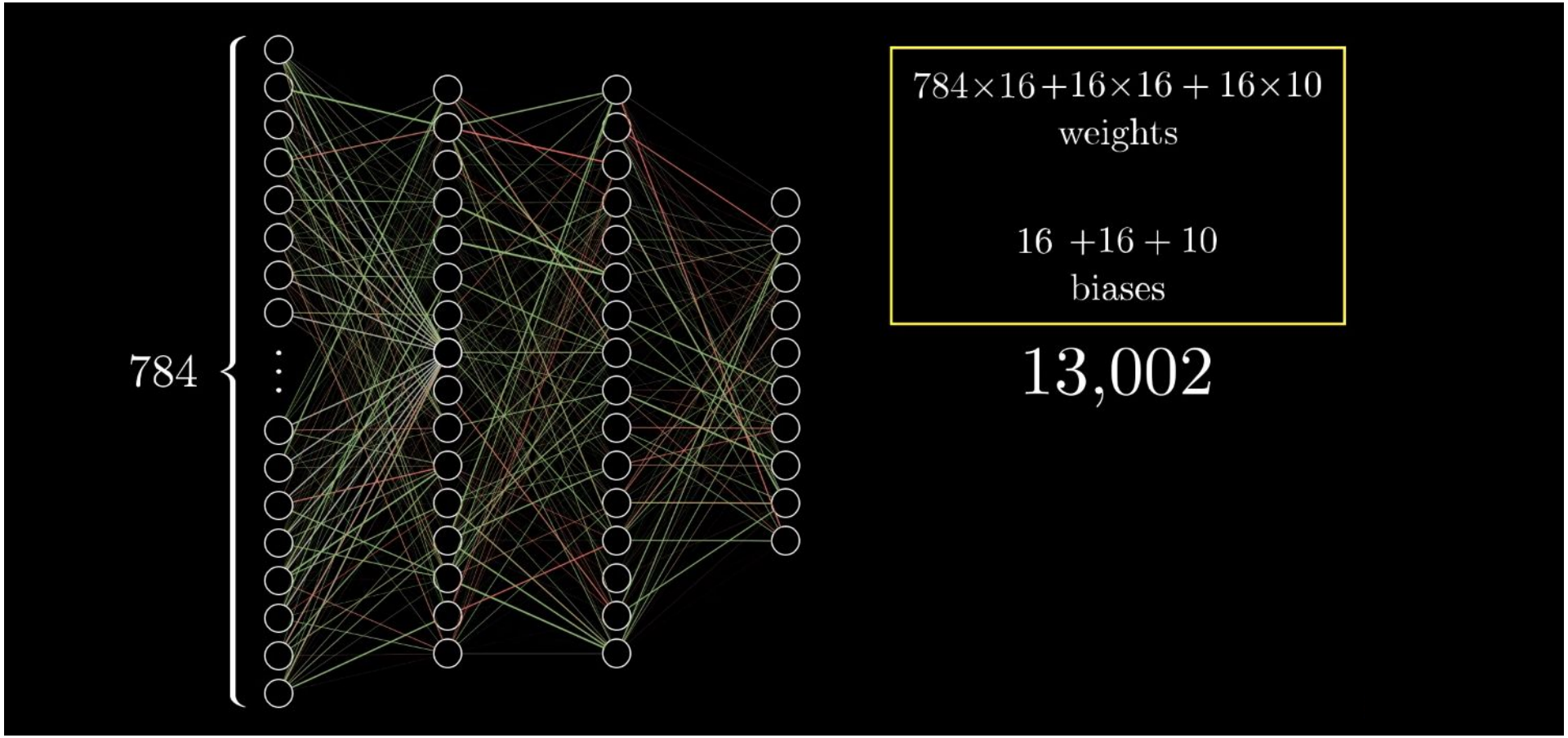
NEURAL NETWORK LEARNING



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NEURAL NETWORK LEARNING

$$a_0^{(1)} = \sigma\left(w_{0,0}\, a_0^{(0)} + w_{0,1}\, a_1^{(0)} + \cdots + w_{0,n}\, a_n^{(0)} + b_0 \right)$$

$$\sigma\left(\begin{bmatrix} w_{0,0} & w_{0,1} & \cdots & w_{0,n} \\ w_{1,0} & w_{1,1} & \cdots & w_{1,n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{k,0} & w_{k,1} & \cdots & w_{k,n} \end{bmatrix} \begin{bmatrix} a_0^{(0)} \\ a_1^{(0)} \\ \vdots \\ a_n^{(0)} \end{bmatrix} + \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_n \end{bmatrix} \right)$$

$$\mathbf{a}^{(1)} = \sigma\left(\mathbf{W}\mathbf{a}^{(0)} + \mathbf{b}\right)$$

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NEURAL NETWORK LEARNING

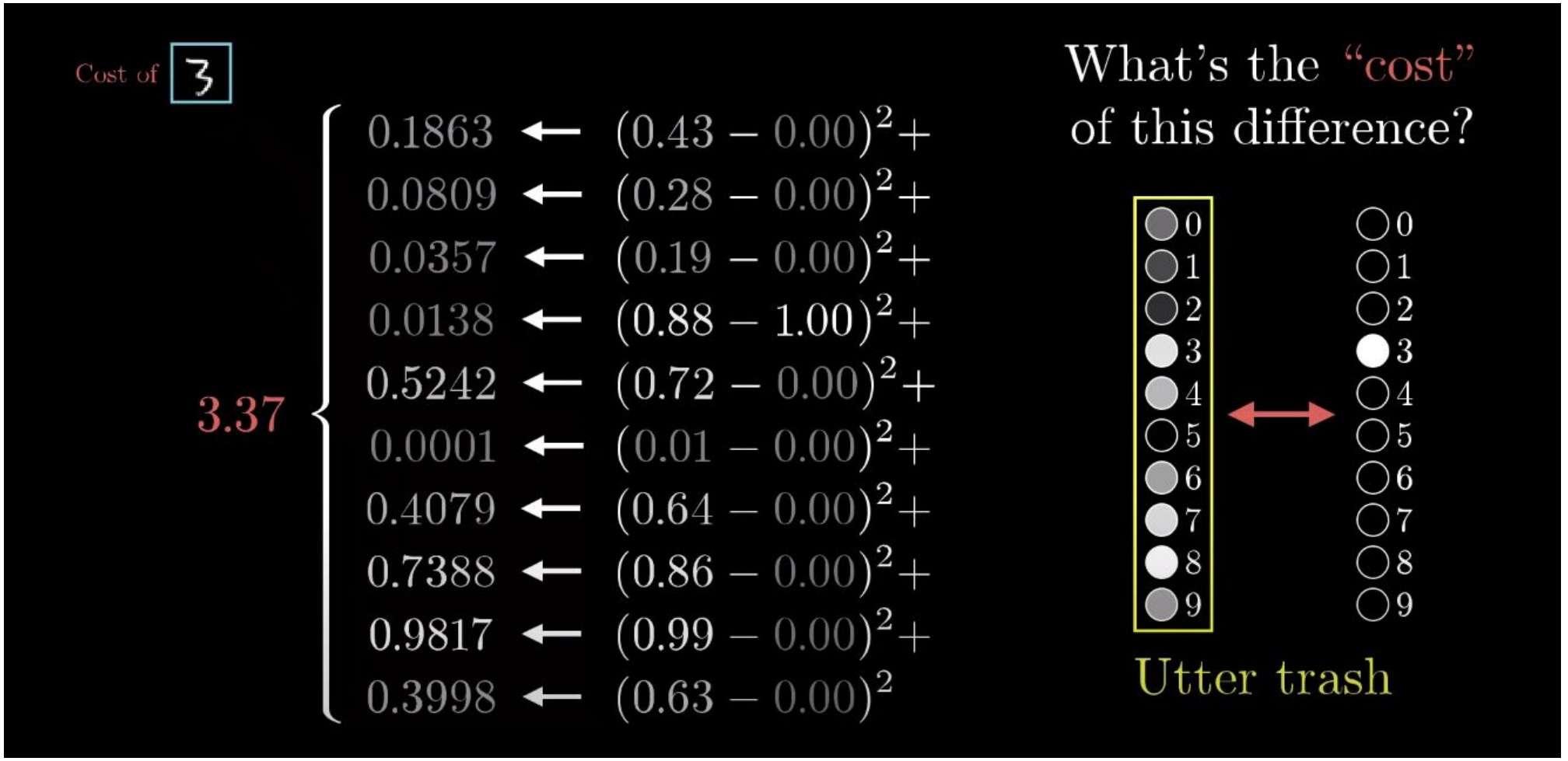
- In this example, each neuron is connected to all the neurons in the previous layer:
  - The *weight* describes the strength of each of those connections
  - The *bias* describes whether the neuron tends to be active or not
- These form a function for each neuron which is transformed into a value between 0 and 1
  - This indicates the activation of the next neuron

https://www.3blue1brown.com/

HOW DOES THIS NETWORK LEARN THE WEIGHTS AND BIASES?

- The *weights* and *biases* are initialized randomly
- The (initially wrong) final output layer is compared to the correct answer to generate a **cost function**
  - The cost function shows the “cost” of the difference - this is the squares of the differences between the output activations and the actual value
- Average cost over all the training examples is used to evaluate how the network performed

HOW DOES THIS NETWORK LEARN THE WEIGHTS AND BIASES?

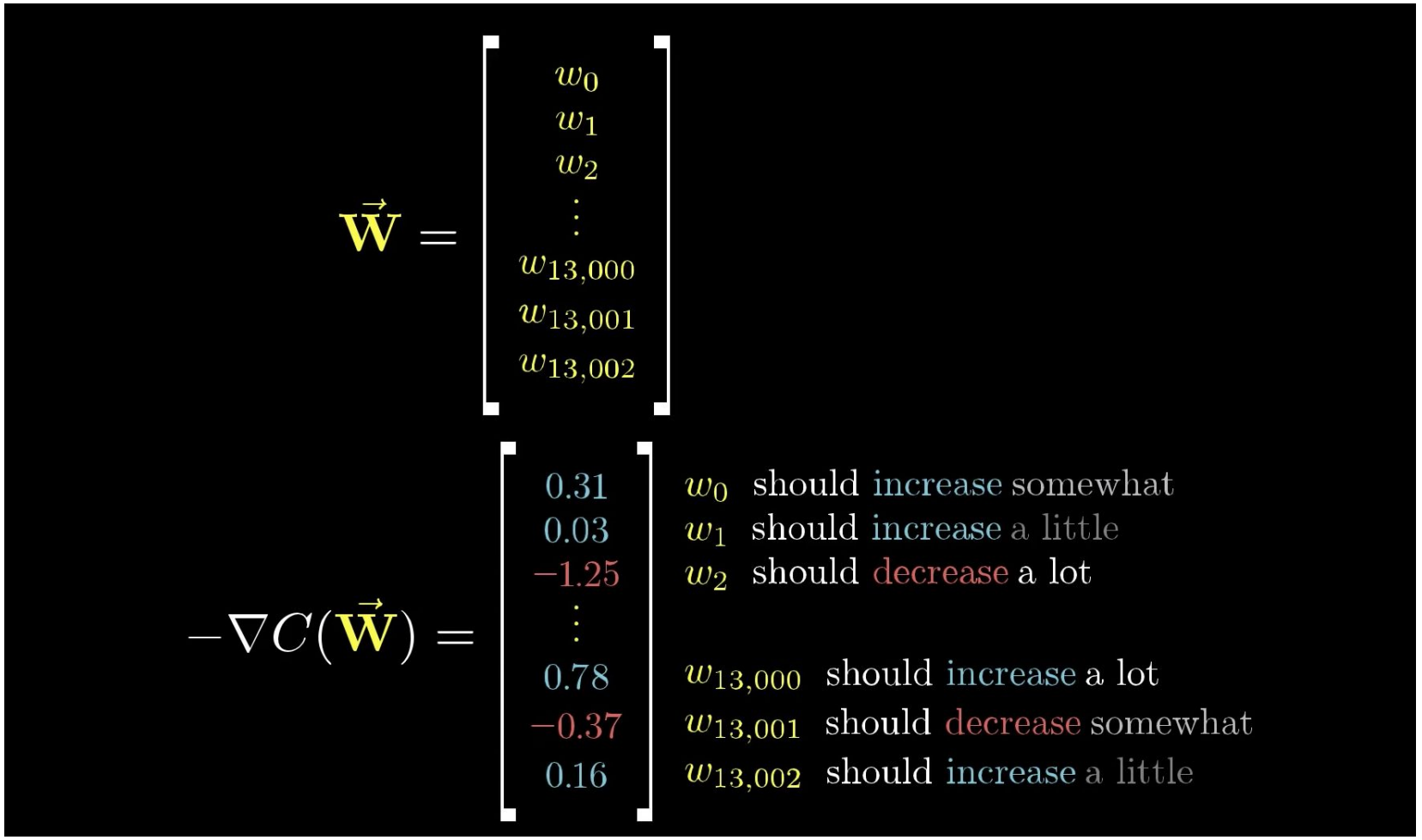


https://www.3blue1brown.com/

COST FUNCTION

- Takes in all weights and biases and returns a single number measuring the network performance
- The cost function needs to be minimized - this is done through gradient descent
- The negative gradient of the cost function tells us what changes to the weights and biases will induce the fastest change to the value of the cost function
- Therefore, the network ‘learning’ is just minimizing a cost function

HOW DOES THIS NETWORK LEARN THE WEIGHTS AND BIASES?



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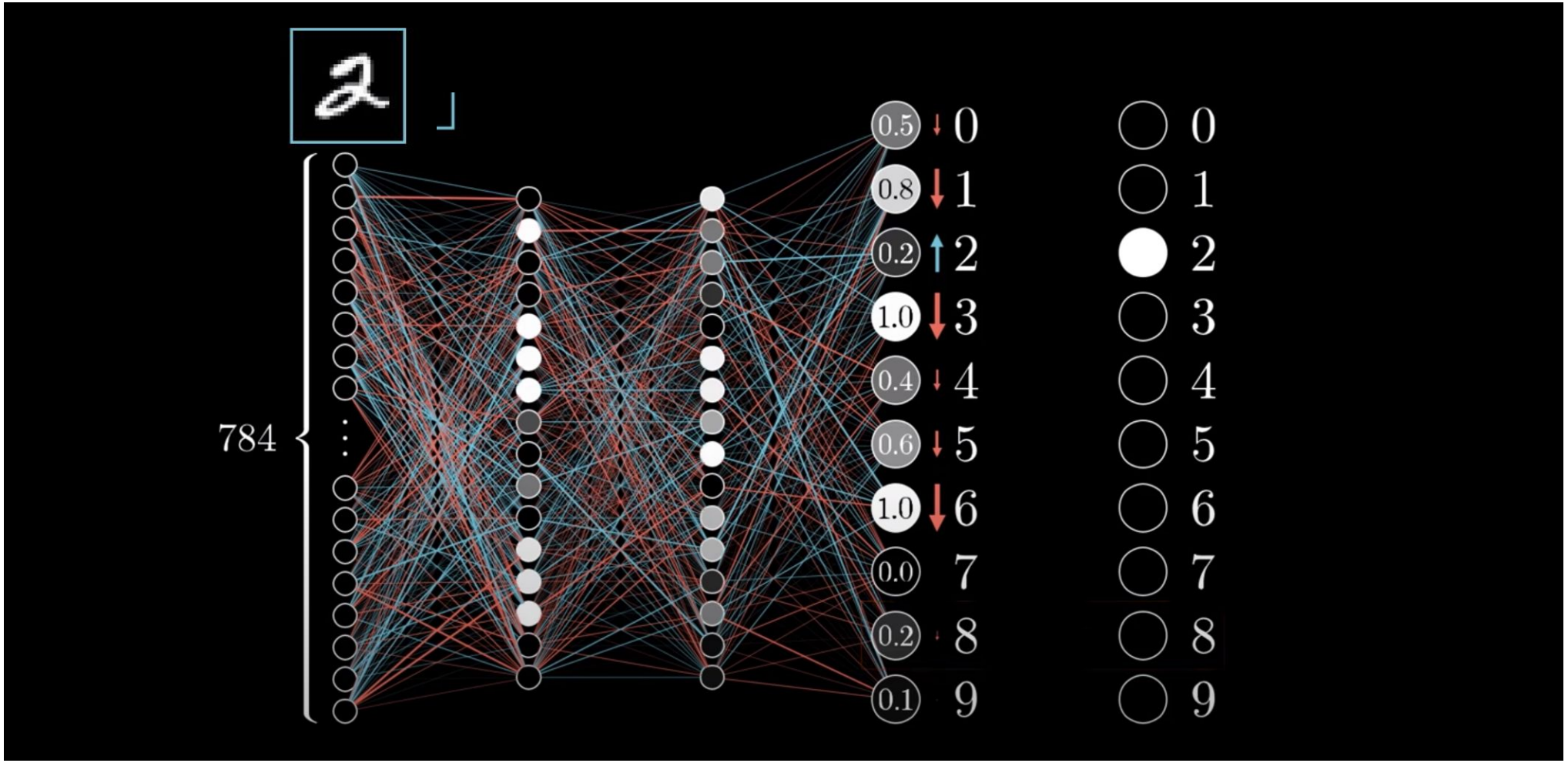
BACKPROPAGATION

- “Backward propagation of errors”
- Algorithm for calculating the gradient of the error function, done so from the last layer to the first layer
- Essentially determines how a single training example would like to alter the weights and biases, based on the cost function, including what relative proportions of those changes cause the most rapid decrease to the cost

BACKPROPAGATION



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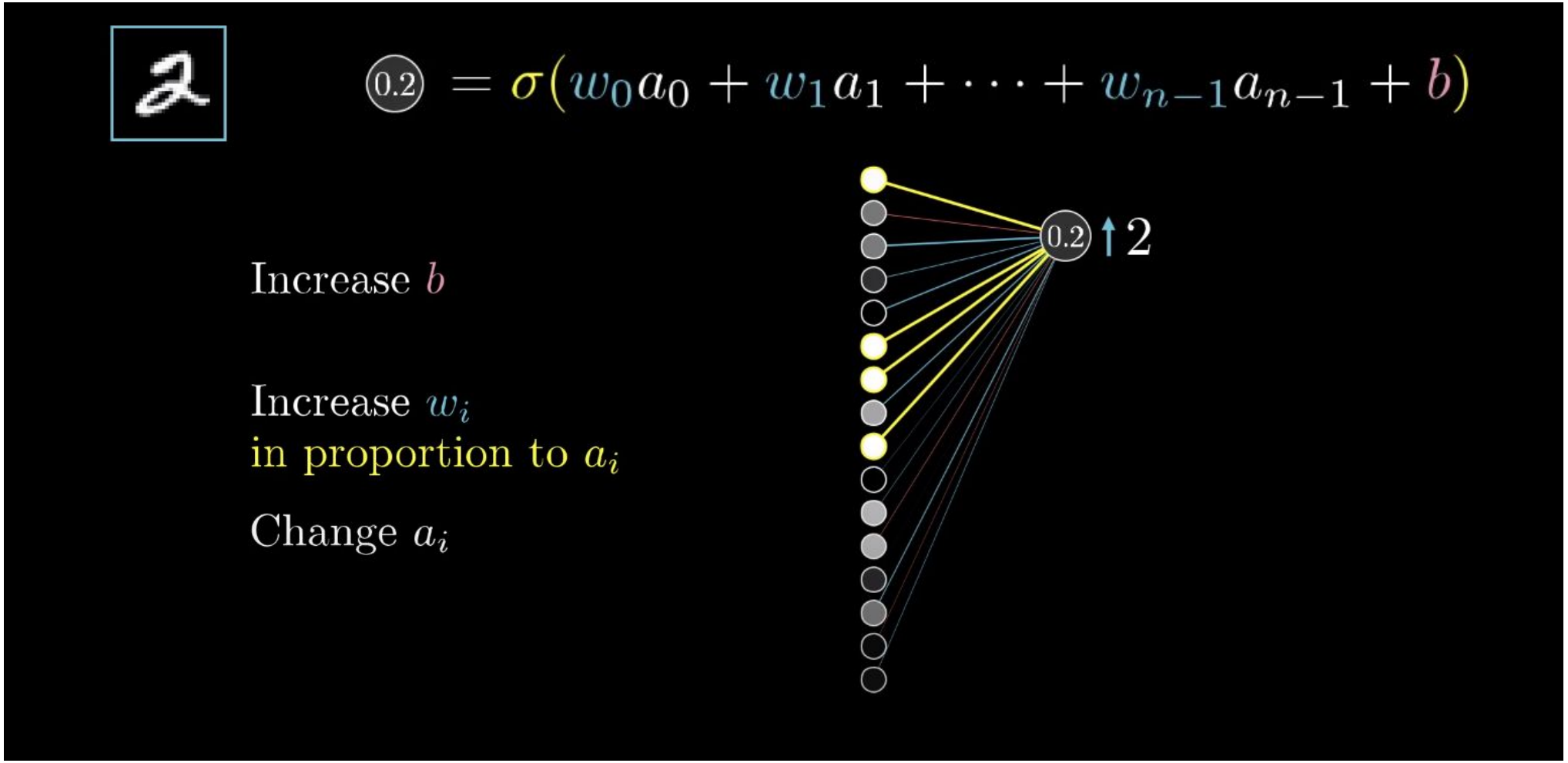

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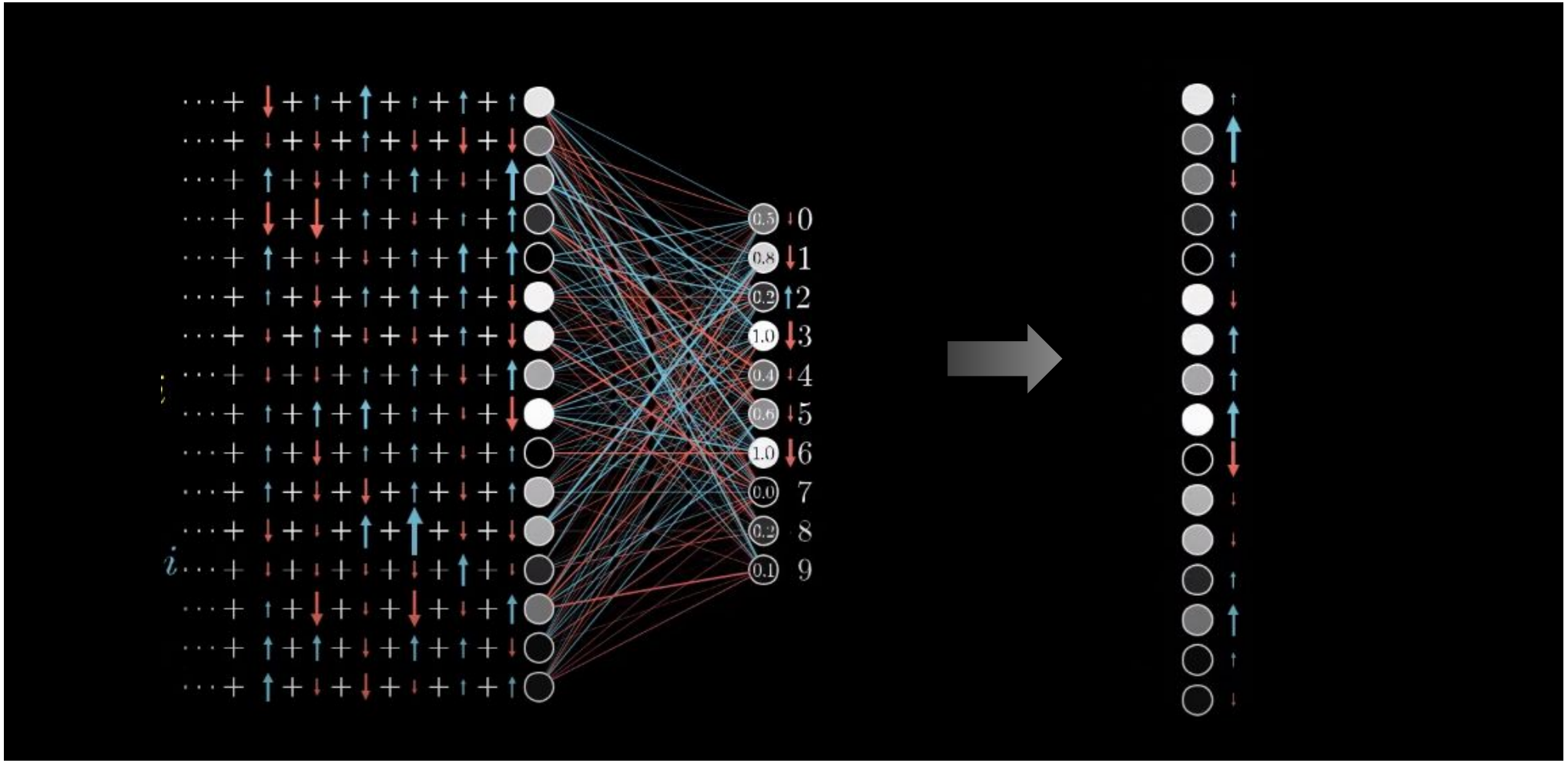

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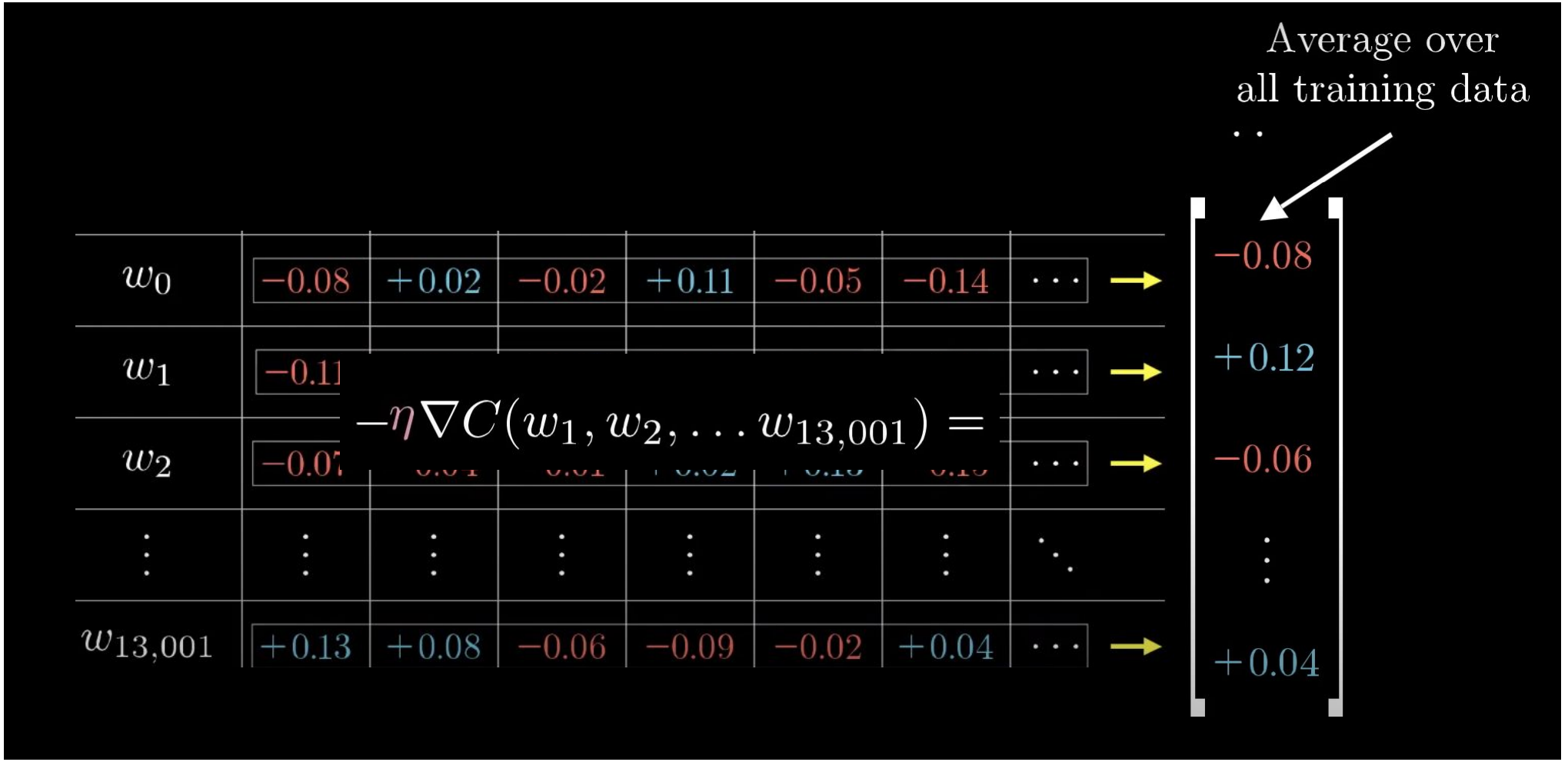
GRADIENT DESCENT



https://www.3blue1brown.com/

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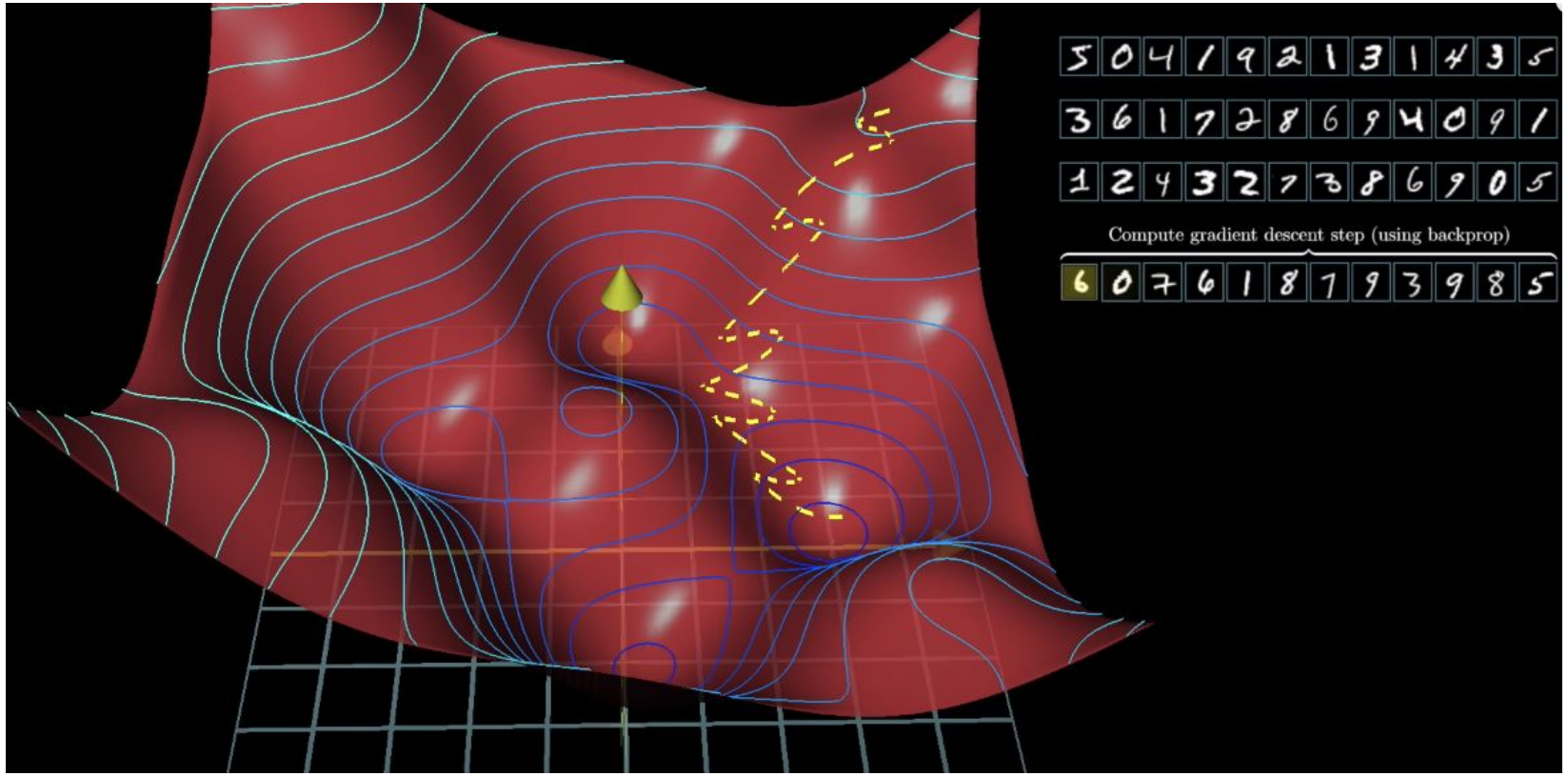
STOCHASTIC GRADIENT DESCENT

Much faster to calculate

1. Divides training data into mini-batches
2. Compute gradient descent step
3. Uses the approximation instead of the actual gradient



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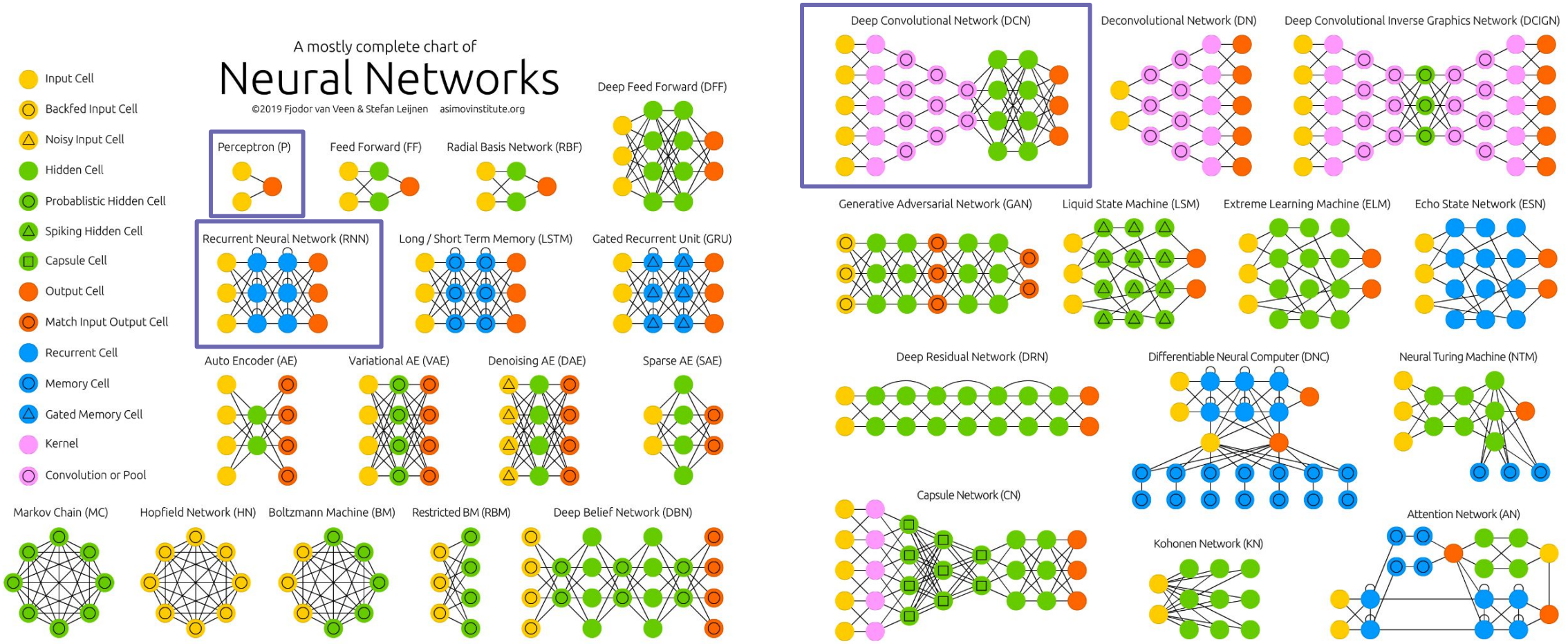
TYPES OF NETWORKS



https://www.asimovinstitute.org/neural-network-zoo/

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MULTILAYER PERCEPTRON

- One perceptron for each input
  - number of parameters rapidly becomes unmanageable
- Reacts differently to shifted versions of an input
  - i.e. the image needs to be in the same place each time
- Spatial information is lost - does not take into account pixel position and correlation with neighbors

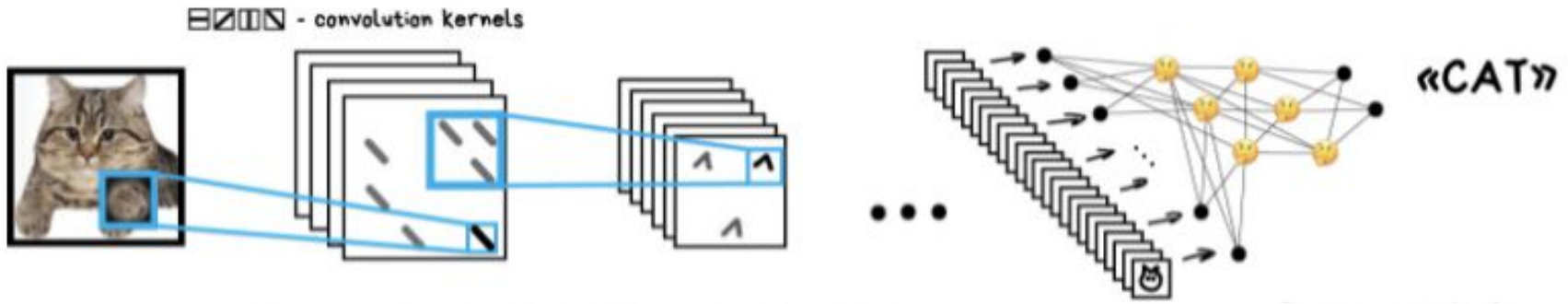
https://www.3blue1brown.com/

CONVOLUTIONAL NEURAL NETWORKS

Most commonly used for pictures and videos in tasks such as identifications, style transfer, enhancing images, slo-mo effects, etc

Solved the problem of hand-crafting features

Assembles patterns of increasing complexity using smaller and simpler patterns



https://vas3k.com/blog/machine_learning/

RECURRENT NEURAL NETWORKS

Best for sequential data like music or text, used for speech recognition, voice synthesis

Idea is to add memory to each neuron - so they get not only info from the previous layer but also from themselves in the previous pass

Neuron can reset when memory is not longer needed, leaving the connection

PyTorch Overview

DEEP LEARNING IN PYTHON

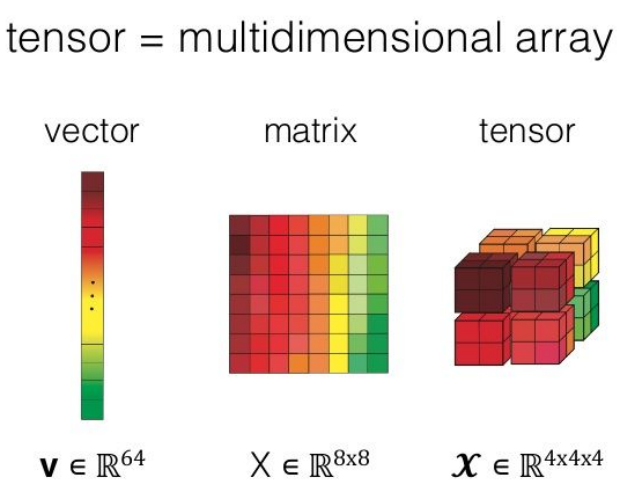
- Theano
- Keras
- TensorFlow
- PyTorch
- MXNet, Lasagne

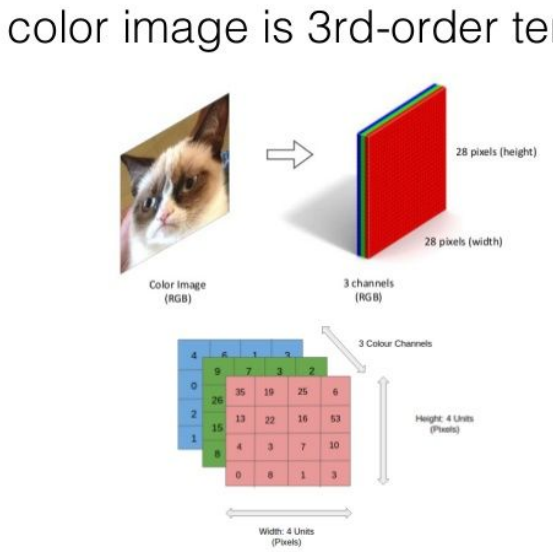
PYTORCH OVERVIEW

- Easy debugging - can be used with many standard Python debugging tools
- Data parallelism - distribute work among CPU/GPU cores
- Many built in loss functions, optimizers, transformations, and easy to build custom data loaders/transformers
- Large community, used in many research papers and online courses

TENSORS

- Data structure similar to arrays and matrices
- Used to encode the input (i.e. pixel info) and output (classes)
- Share underlying memory with numpy arrays but can run on GPUs





https://www.slideshare.net/BertonEarnshaw/a-brief-survey-of-tensors

DATALOADERS AND TRANSFORMS

- Dataloaders let us pass samples in “minibatches”, reshuffle the data at every epoch to help with generalization, speed up retrieval, and set the number of workers to take full advantage of all of the GPUs
- Transforms - modify data or labels
  - Avoid overfitting and increase the number of training data
  - Crop, resize, normalize color channels, change to grayscale, etc
  - `torchvision.transforms` - offers several commonly used transforms

ACTIVITY: EXPLORE TRANSFORMS

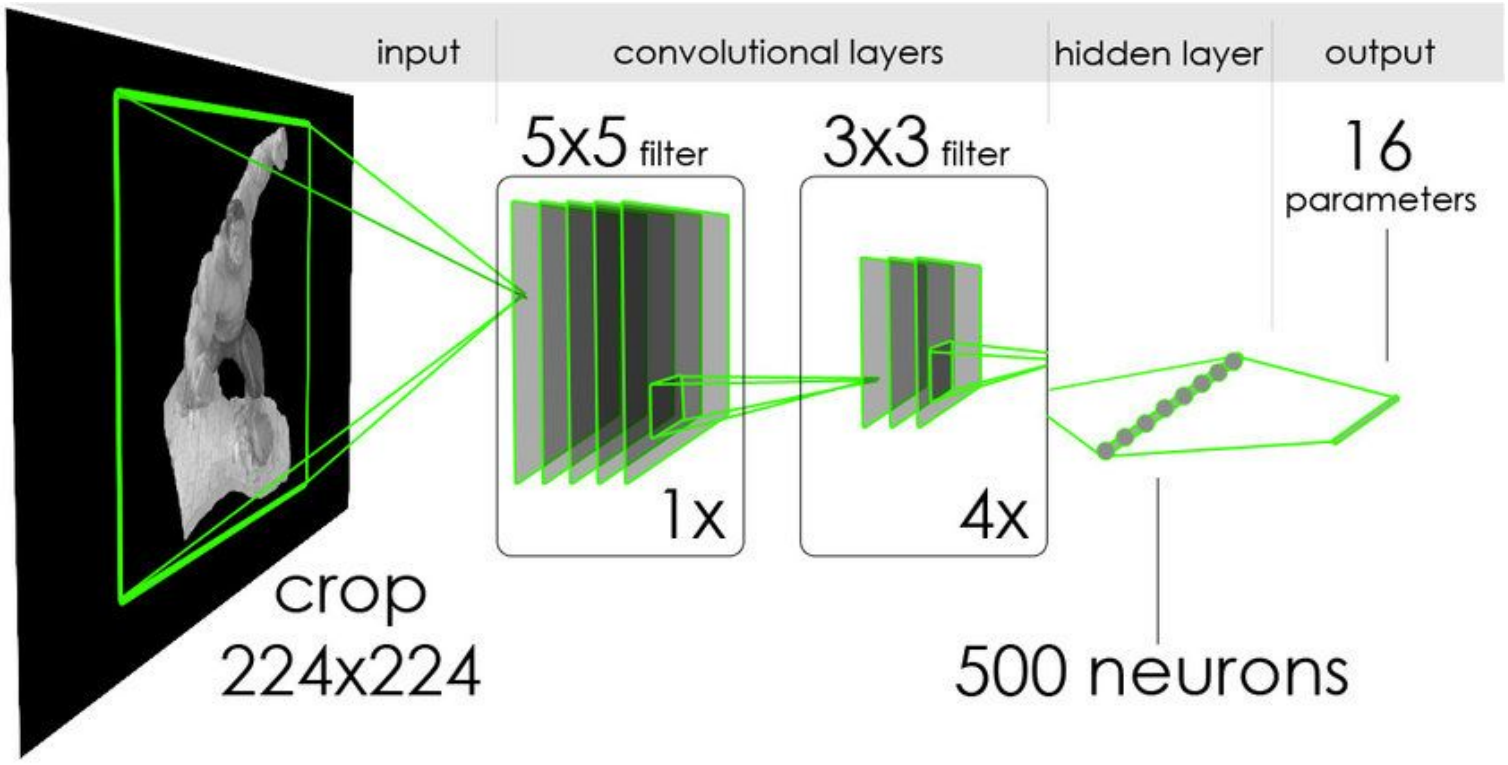
1. Open notebook ‘2-Load-Data-PyTorch.ipynb’
2. In your breakout room, try different transforms to see how they change the images

Deep Learning in Practice

INPUT AND OUTPUT LAYERS

Input layer - features of the image

Output layer - dataset labels



https://www.researchgate.net/publication/321260305_Learning_Lightprobes_for_Mixed_Reality_Illumination

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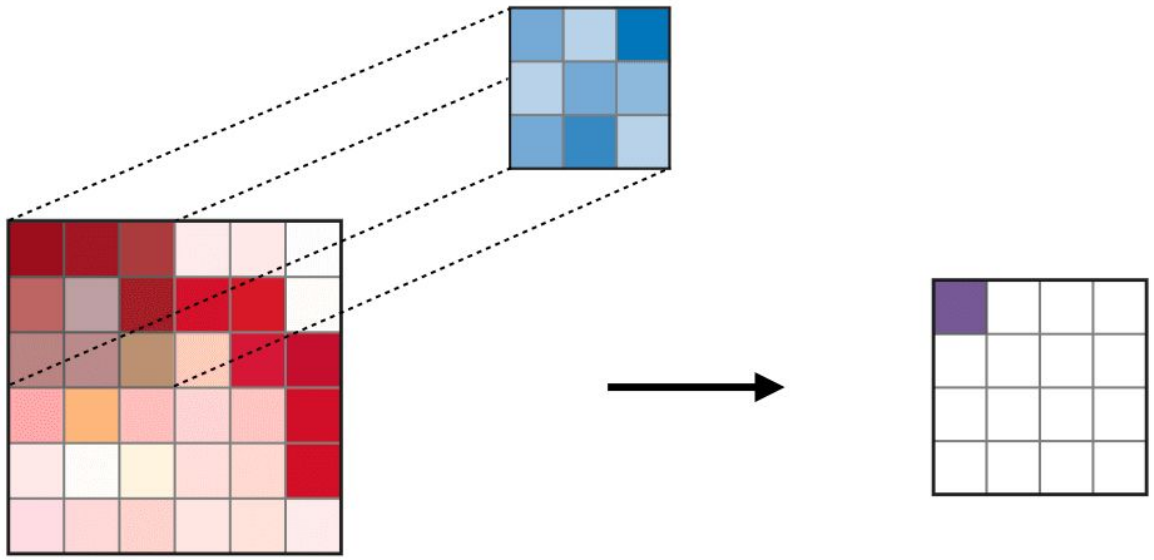
CONVOLUTIONAL LAYERS

Filters scan across the input and calculate a value using a convolution operation

Each filter can be related to anything - for example one could locate tails

There are multiple filters which results in a 3D output



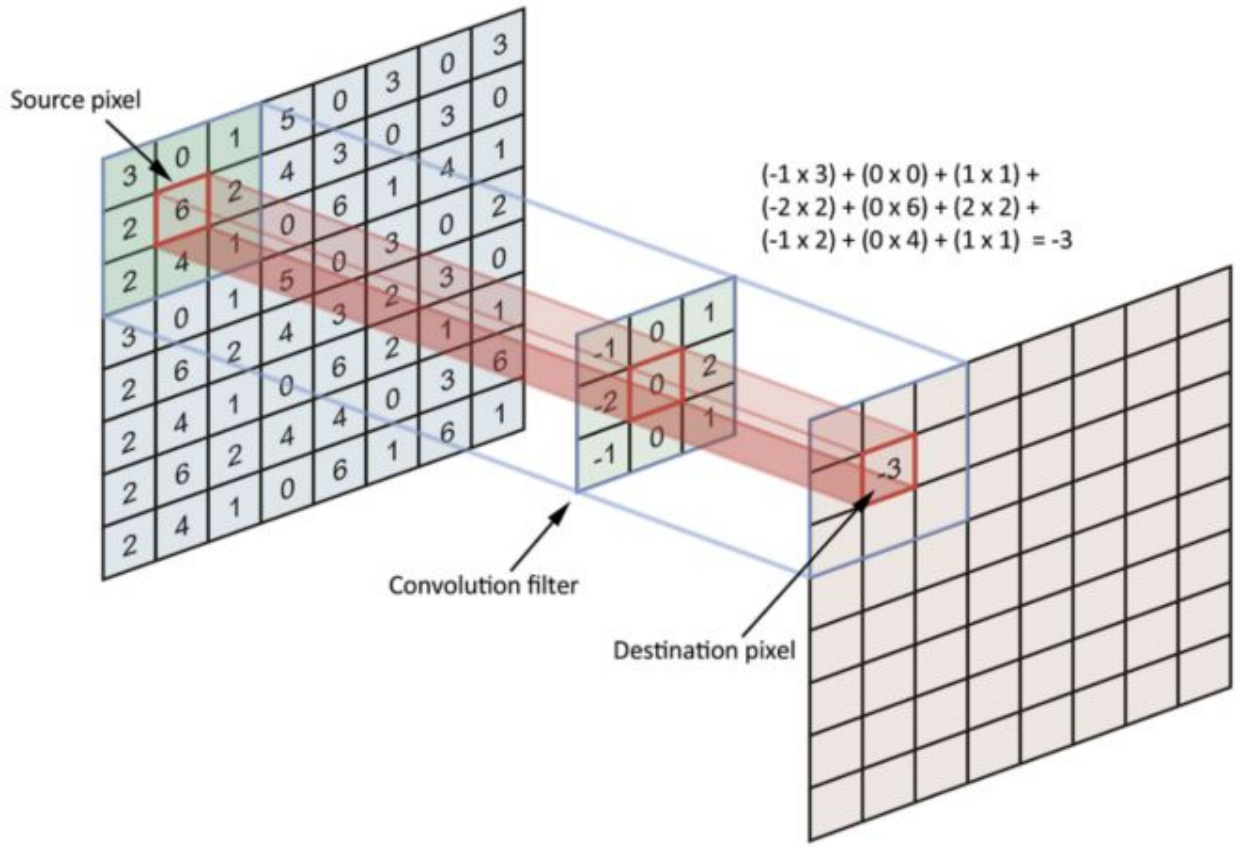
https://stanford.edu/~shervine/teaching/cs-230/cheatsheet-convolutional-neural-networks

CONVOLUTIONAL LAYERS

Each 2D slice of the filters is called a kernel

A feature map is generated for each kernel

These are passed through an activation function - determines if a given features is present at that location



https://towardsdatascience.com/simple-introduction-to-convolutional-neural-networks-cdf8d3077bac

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CONVOLUTIONAL LAYERS

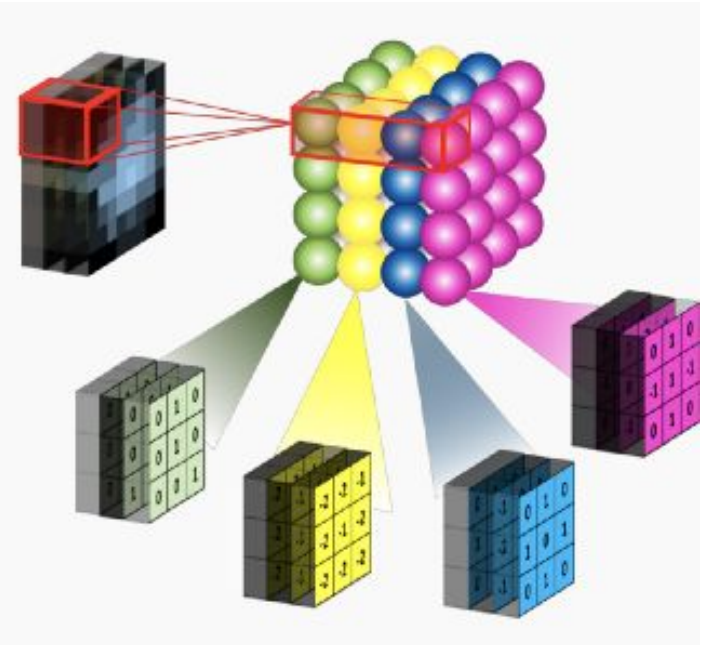
Summary:

Filters are composed of kernels (learned) and extract features

One bias per filter

Applied to original image or feature map from another layer

An activation function is used on every value of the feature map



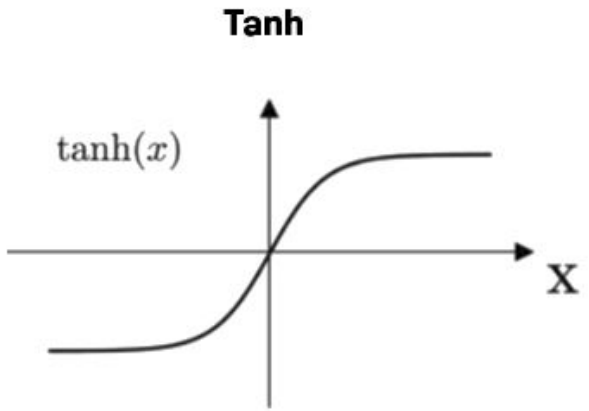
https://towardsdatascience.com/simple-introduction-to-convolutional-neural-networks-cdf8d3077bac

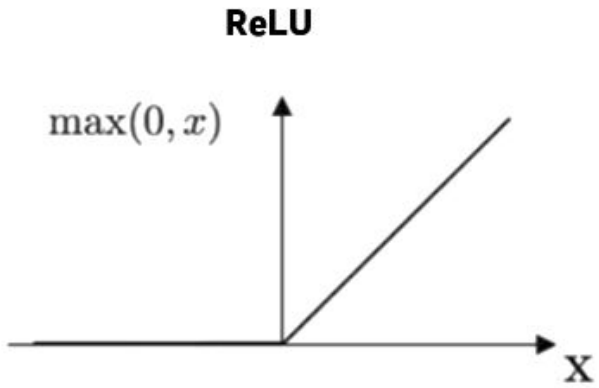
ACTIVATION FUNCTIONS

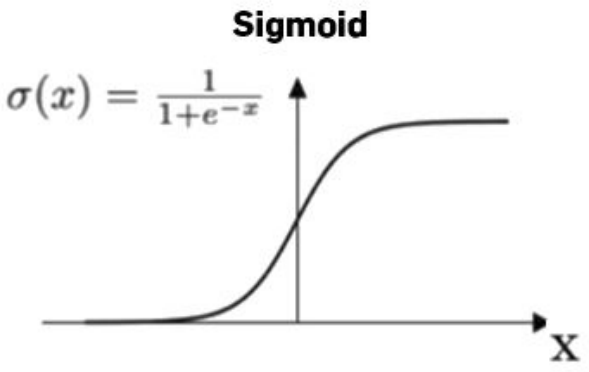
Adds non-linearity

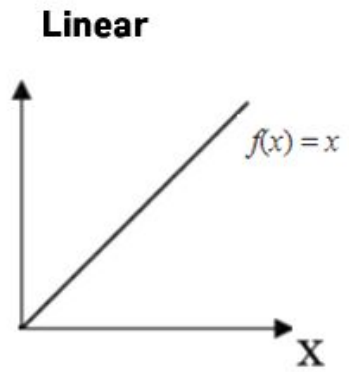
ReLU is typically a good start

- Cheap
- Stable









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WHY DO WE NEED NON-LINEARITY?

A neural network without an activation function is essentially just a linear regression model

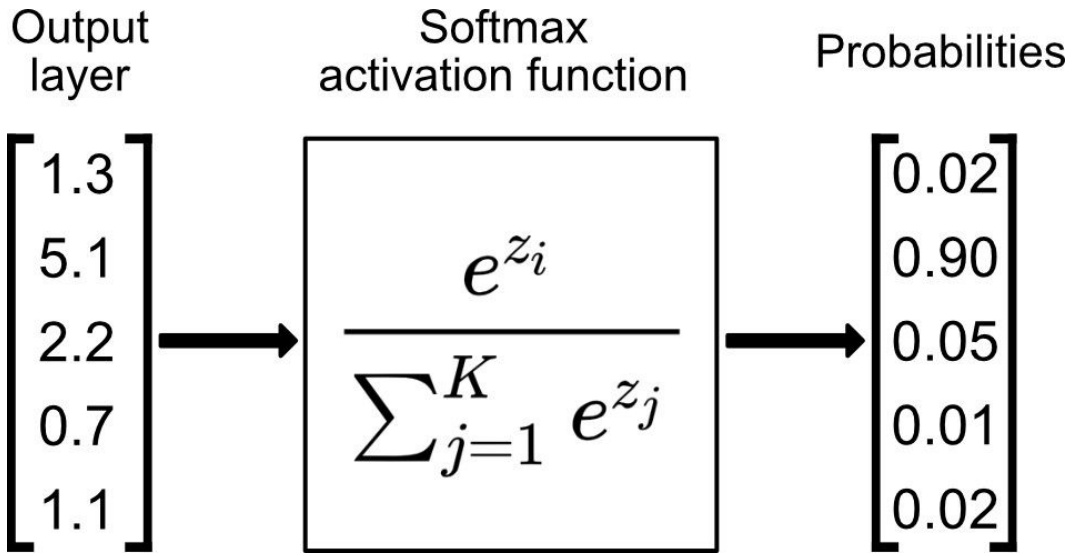
The non-linear transformation to the input making it capable to learn and perform more complex tasks

https://www.3blue1brown.com/

ACTIVATION FUNCTIONS - SOFTMAX

Used for building a multi-class classifier

Different from a Sigmoid function because it ensures the sum of the outputs along channels is 1



https://towardsdatascience.com/softmax-activation-function-explained-a7e1bc3ad60

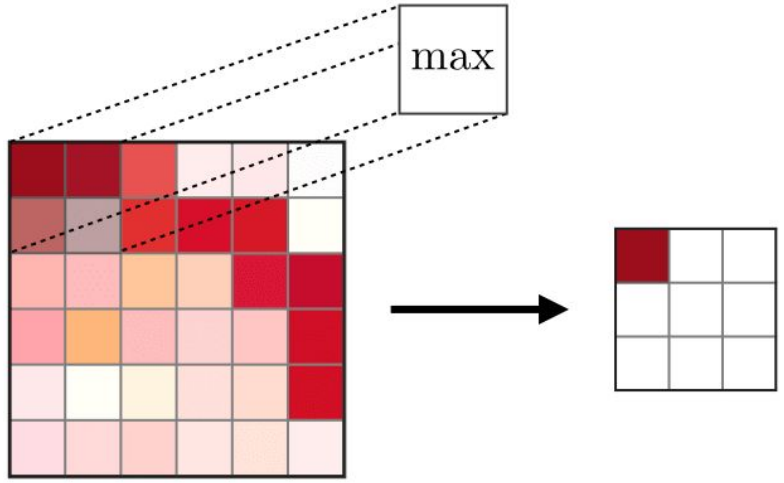
POOLING LAYER

Used to reduce dimensionality, typically applied after a convolution layer

Max pooling (most common) - selects the largest values on the feature maps and passes these to next layer

Outliers are when the network sees the feature

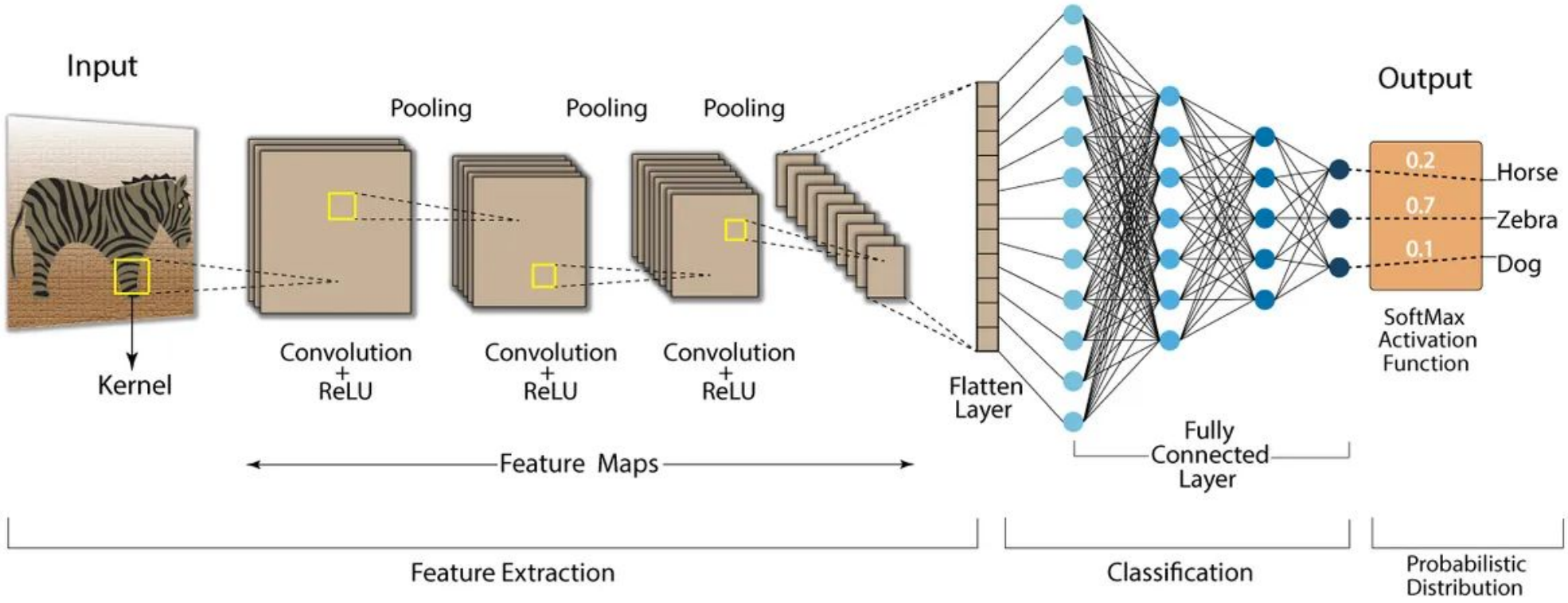
Average pooling - selects the average value in a filter region



https://stanford.edu/~shervine/teaching/cs-230/cheatsheet-convolutional-neural-networks

FULLY CONNECTED LAYERS

Aggregates input from the final feature maps



https://developersbreach.com/convolution-neural-network-deep-learning/

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MODEL LAYERS IN PYTORCH

`torch.nn` - PyTorch's basic building blocks for graphs

- various functions for convolutional, pooling, and many other types of layers
- non-linear activations
- loss functions

`torch.nn.Module` - basic class for all neural network modules

`torch.nn.Sequential`- sequential container

AUTOGRAD

Backpropagation is used to calculate the gradient of a weight

For each iteration, several gradients are calculated and something called a computation graph is built for storing these gradient functions

PyTorch does it by building a Dynamic Computational Graph (DCG)

You may disable gradient tracking:

- To mark some parameters in your neural network at frozen parameters (common when using a pre-trained network)
- To speed up computations when you are only doing forward pass

TRANSFER LEARNING (PRE-TRAINED CNNS)

Large networks trained on ImageNet (image database) contain information in the final convolutional layers or early fully-connected layers about:

- How an image is composed and
- Combinations of edges/shapes

Fixed feature extractor - freeze all layers except the last full-connected layer to keep the features but not the classifier

Fine-tuning the model - train with a small learning rate to ensure it doesn't 'unlearn' previous knowledge

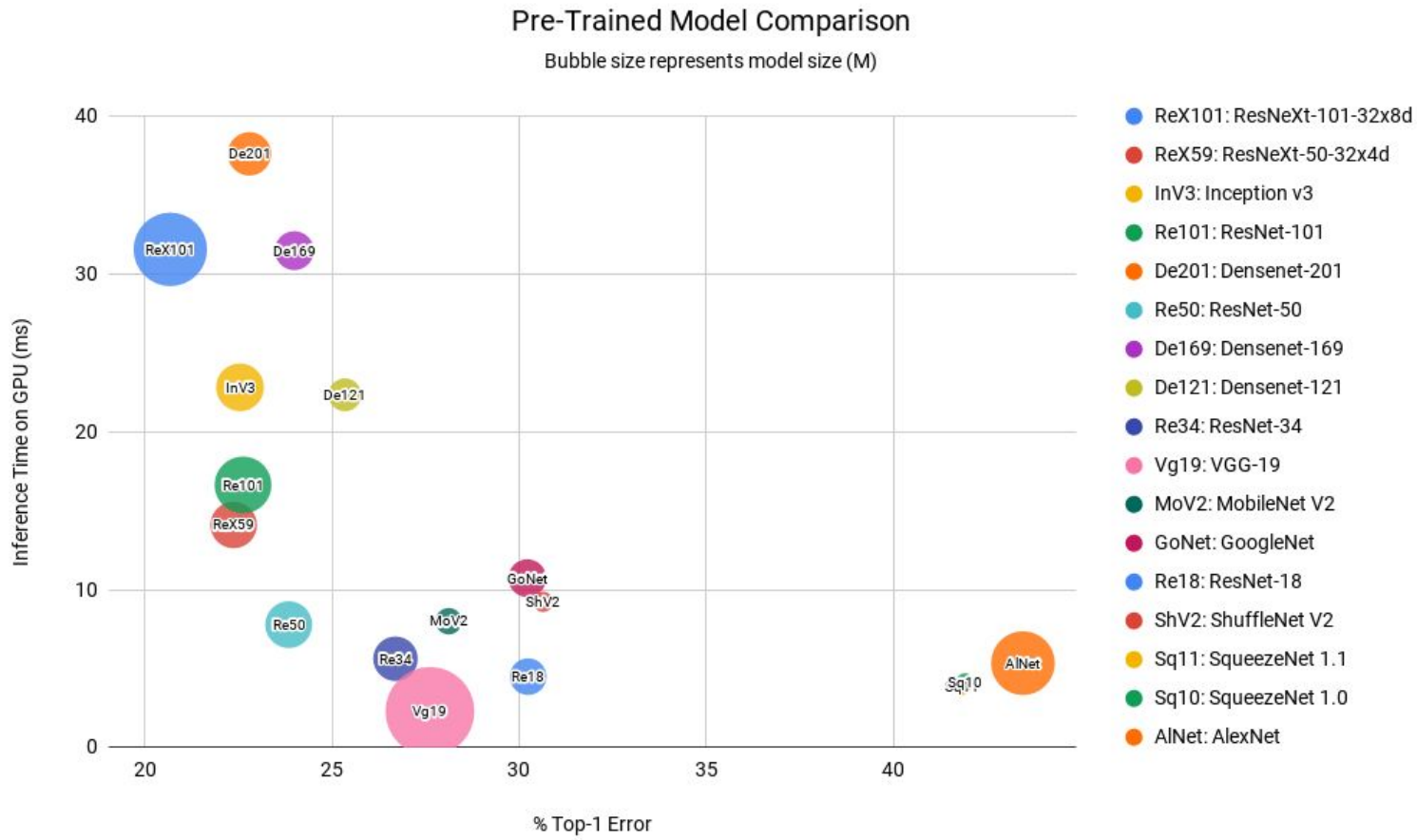
TRANSFER LEARNING IN PYTORCH

PyTorch `torchvision.models` - contains image classification models of various architectures with the option for `pretrained=True` to download the weights, shown here

All pre-trained models expect input images normalized in mini-batches of 3-channel RGB images in shape (3 x H x W) where H and W are at least 224 and then mean=[0.485, 0.456, 0.406] and std=[0.229, 0.224, 0.225]

Check out this article for more information on reproducibility and considerations before using pre-trained models

TRANSFER LEARNING IN PYTORCH



https://learnopencv.com/pytorch-for-beginners-image-classification-using-pre-trained-models/

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GPUS

Perform multiple, simultaneous computations enabling the distribution of training processes

Large number of simple cores vs a few complicated cores (CPU)

Note that GPUs can have a bandwidth bottleneck issue - transferring large amounts of data to the GPU can be slow

- Optimizing this process is covered in the tutorial notebooks

MACHINE LEARNING REVIEW

Clean and explore your data

Imbalanced classes - use sampling to rebalance

Train/Test sets - use stratification to ensure distribution of classes in both sets, don't apply transforms to test set

Encode categorical variables (one-hot, etc)

LOSS FUNCTIONS

Regression

- Mean-squared error loss
- Mean absolute error loss

Binary Classification

- Binary cross entropy
- Hinge Loss

Multi-Classification

- Multi-class cross entropy
- Kullback Liebler Divergence

CROSS ENTROPY

Default loss function

Cross-entropy will calculate a score that summarizes the average difference between the actual and predicted probability distributions for all classes in the problem

The score is minimized and a perfect cross-entropy value is 0

Note: Binary cross-entropy is a special case for two classes.
`nn.BCEWithLogitsLoss` can take raw unnormalized logits, used in our tutorial because of one hot encoding

KULLBACK-LEIBLER DIVERGENCE

Also called relative entropy, this is a common form of statistical distancing

Measures the difference between two probability distributions -

- Entropy tells you how much information is in a probability distribution given some data
- Therefore you can find out how much is *lost* when you change the distribution

ACTIVITY: BUILD CNN ARCHITECTURE AND TRAIN MODEL

1. Open notebook ‘3-Build-Model.ipynb’ and run each cell to see the CNN architecture and training code
2. Open notebook ‘4-Improve-Performance.ipynb’ and run each cell to see the increases in speed after a optimization techniques have been applied

Optimizing Model Performance

EPOCHS

The number of times the learning algorithm will evaluate the entire training dataset

More epochs means more time to converge, but also more training time

Too many epochs may lead to overfitting

OPTIMIZERS

Stochastic Gradient Descent - calculates gradients on batches of examples at a time

Adam - stands for adaptive moment estimation, utilizes momentum by adding fractions of previous gradients to the current one

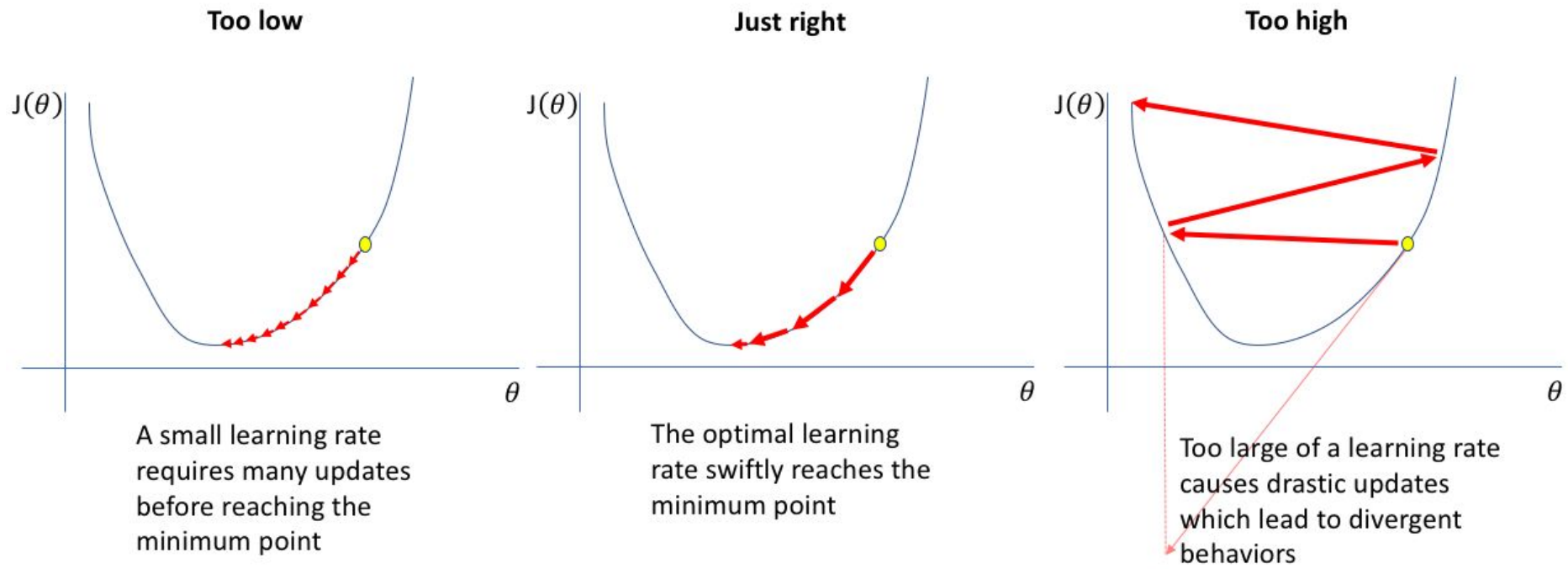
AdaGrad - adapts the learning rate to individual features, so some of the weights will have different learning weights

- good for sparse data
- learning rate tends to get really small

RMSProp - special version of AdaGrad but only accumulates gradients in fixed window

LEARNING RATE

Hyperparameter between 0 and 1 that controls how much to change the model in response to to the estimated error each time the weights are updated



https://www.jeremyjordan.me/nn-learning-rate/

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LEARNING RATE

Decaying Learning Rate - decreasing the learning rate with increases in epochs

Scheduled Learning Rate - dropped at a predetermined frequency to quickly move to a range of ‘good’ values and then fine tune

Adaptive Learning Rate - monitoring the performance of the model on the training dataset by the learning algorithm and adjusting the learning rate in response

- Methods include Adam (most popular), AdaGrad, and RMSProp

LAYER PARAMETERS

Convolutional layers - number and size of kernels (most important), activation function, stride, padding, regularization type and value

Pooling layers - stride, size of window

Fully connected layers - number of nodes, activation function (depends on role of layer, typically ReLu or softmax)

ACTIVITY: MODEL TUNING COMPETITION

1. Open notebook ‘5-Hyperparameter-Tuning.ipynb’
2. In your breakout room, try different changes to hyperparameters/optimizers/etc.
3. When you’re happy with your result, run the last cell to submit your results to a leaderboard
    a. You can rerun the cell to overwrite your old result

Summary

SUMMARY

While it is important to understand the parameters of different layer types, you will often use a pre-built architecture

Test out different parameters for number of images, transforms, learning rate, epochs, and optimizers

Optimization for speed can occur when reading and processing images, setting Dataloader parameters, and freezing layers

RESOURCES

Tutorial materials: https://github.com/dominodatalab/DeepLearningTutorial

PyTorch docs - https://pytorch.org/tutorials/

Great visualization videos on math and machine learning concepts - https://www.3blue1brown.com/

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THANKS!

Any questions?

Help us improve! Please fill out our post-training survey here
http://bit.ly/domino_training_survey