UNIVERSITY OF PORTSMOUTH LIGO

Machine Learning

Are machines the next Einstein?

Institute of Engineering and Technology

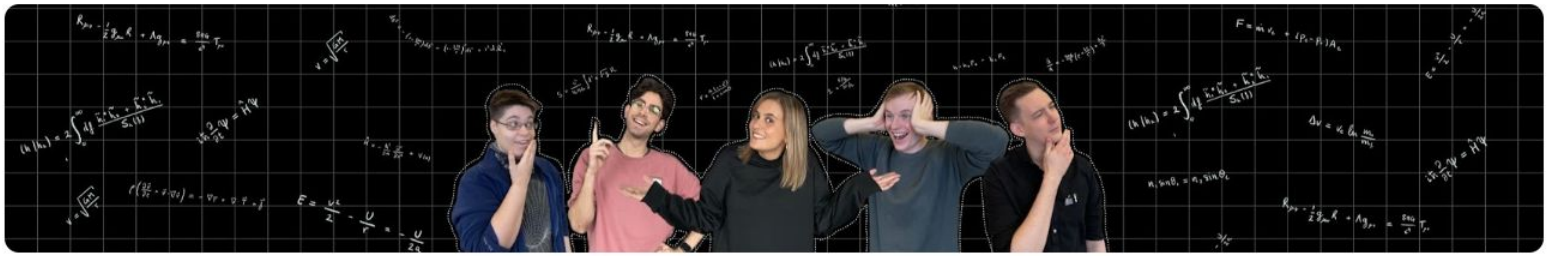
Susanna Green

Image Credit: svstudioart on Freepik

“Even though I am doing an Astrophysics PhD… I oscillate between being a software engineer, machine learning engineer, and a data scientist. Plus I am a content creator!”

– Susanna Green –

physics chat field of view



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How do **YOU** **think** and **learn?**

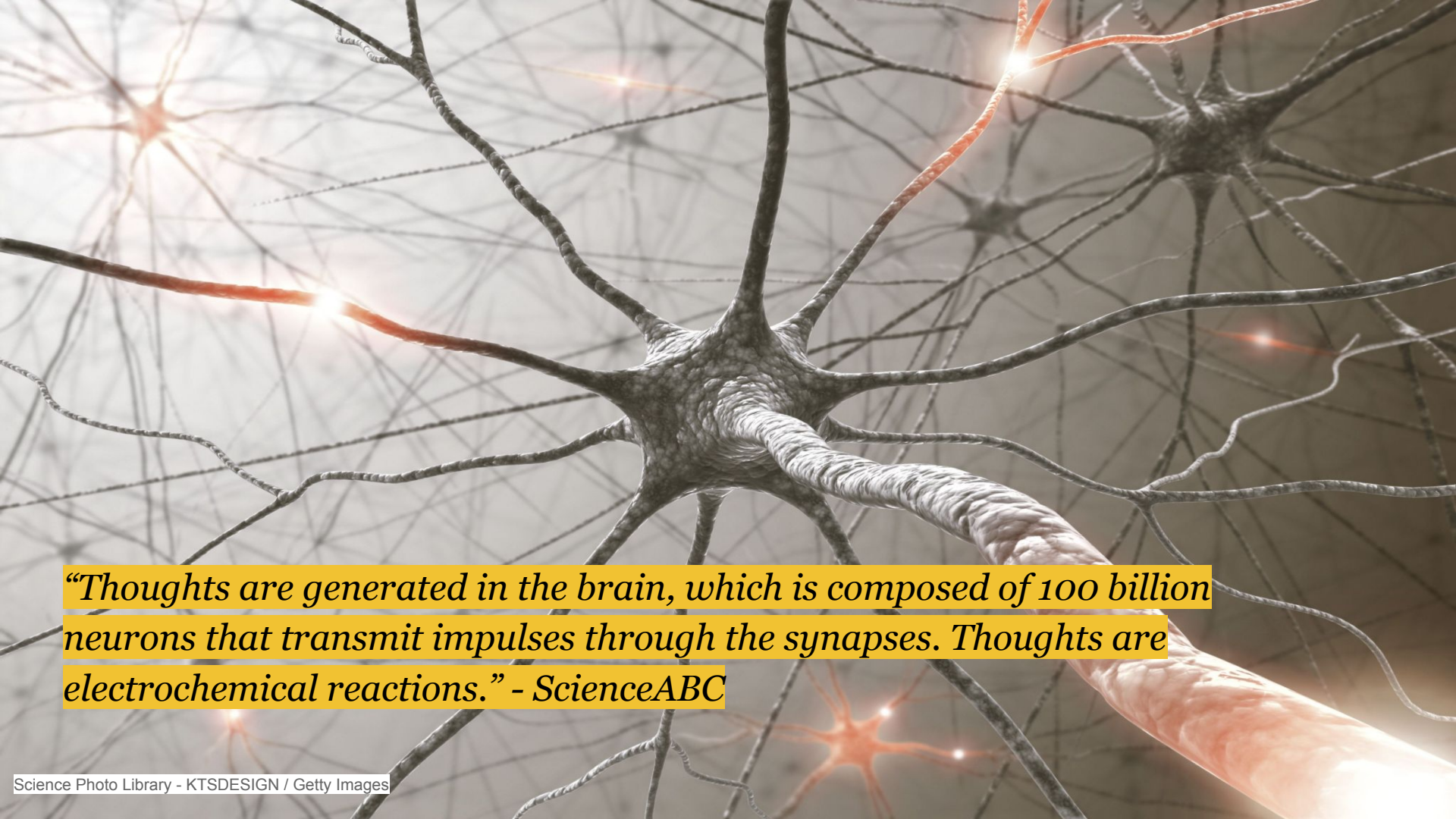
Image by wayhomestudio on Freepik

“Did you know the average person has about 6,200 thoughts per day”

Psychologists at Queen’s University in Kingston, Ontario, 2020 (Credit: Bigthink.com)

A. I have more thoughts than this!!!
B. I have about this many thoughts.
C. I have very few thoughts a day…

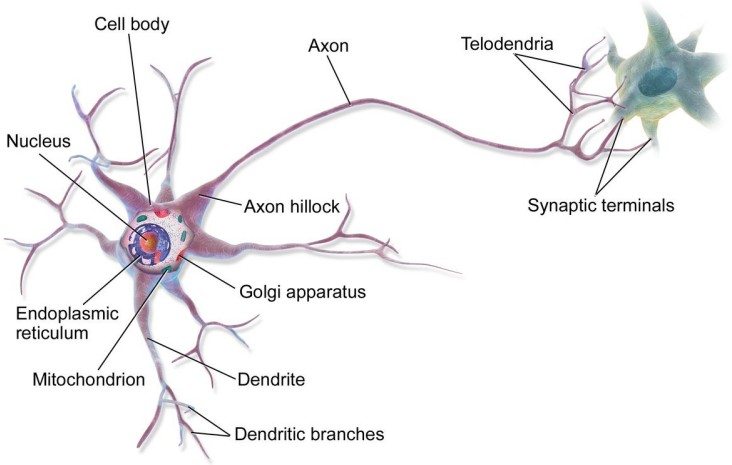
Have you ever thought about your thoughts? Like, what even is a thought?
Like… what are your thoughts made of?
Credit: ScienceABC



“Thoughts are generated in the brain, which is composed of 100 billion neurons that transmit impulses through the synapses. Thoughts are electrochemical reactions.” - ScienceABC

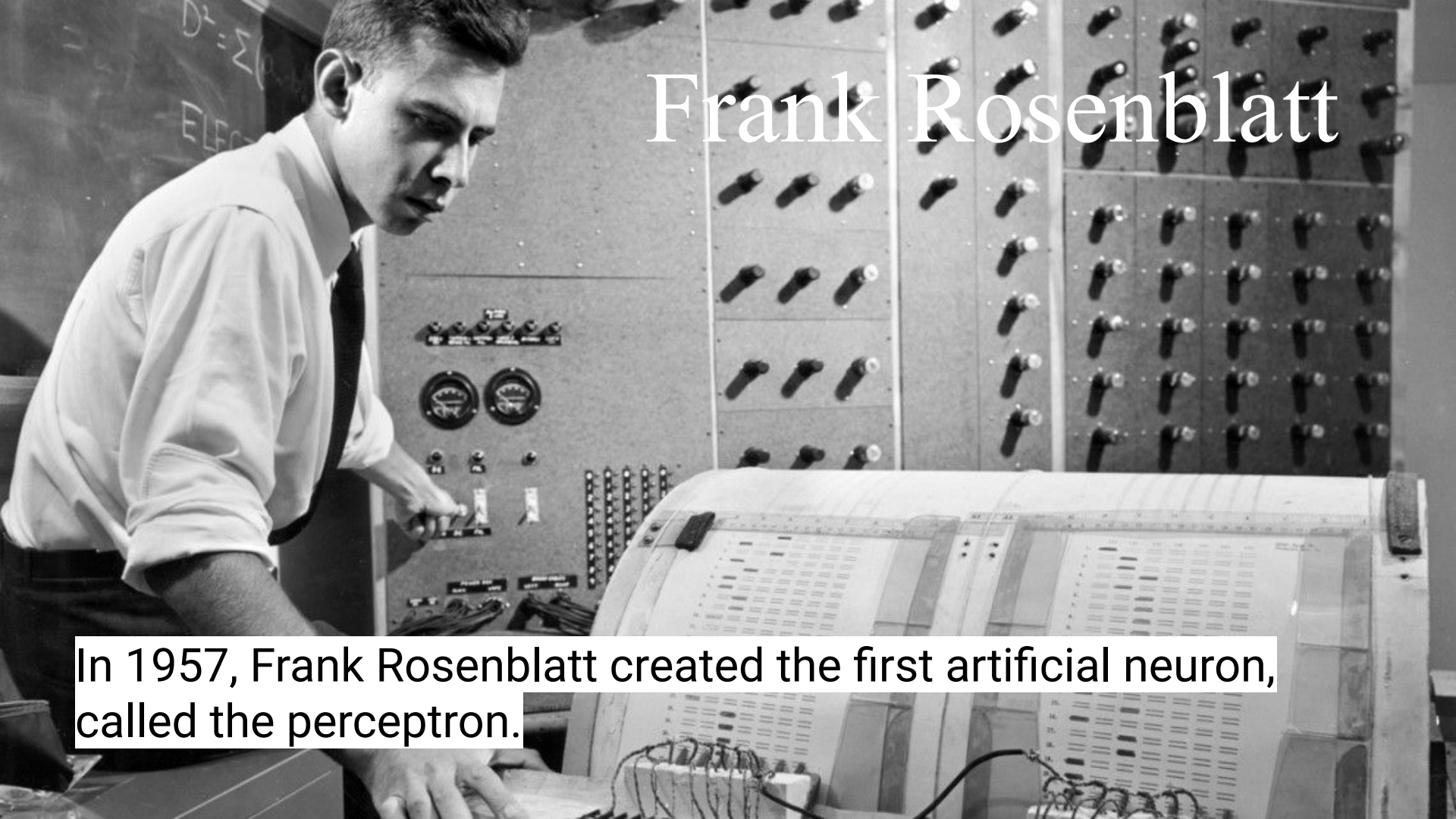
Science Photo Library - KTSDESIGN / Getty Images

Biological neuron



Credit: Wiki

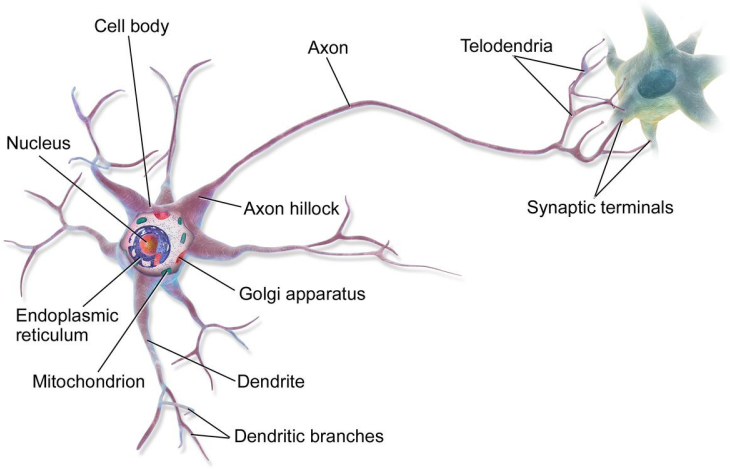
Stimulus → Enough stimulus to send on signal → Signal passed onto the next neuron



Frank Rosenblatt

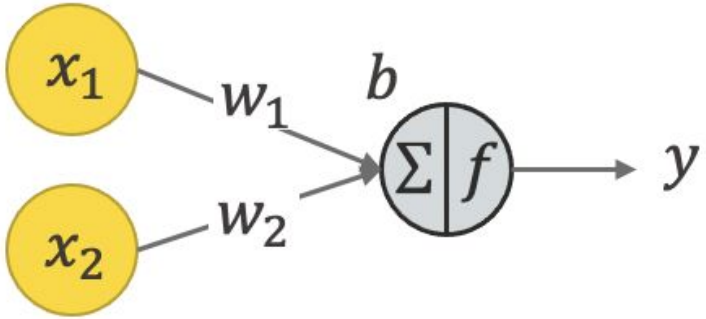
In 1957, Frank Rosenblatt created the first artificial neuron, called the perceptron.

Biological neuron v.s. artificial neuron (perceptron)?



Credit: Wiki

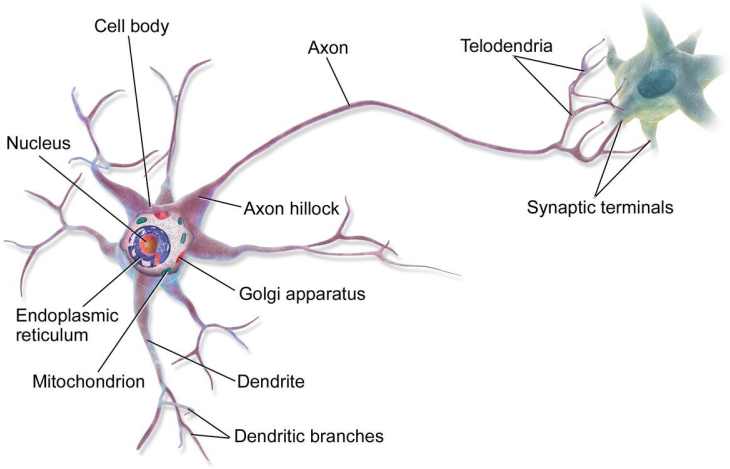
v.s.



Credit: knime.com

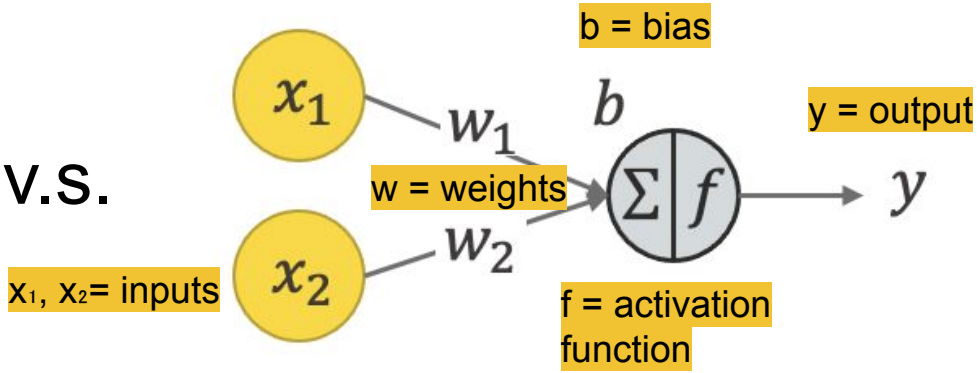
Input → Process → Output

Biological neuron v.s. artificial neuron (perceptron)?



Credit: Wiki

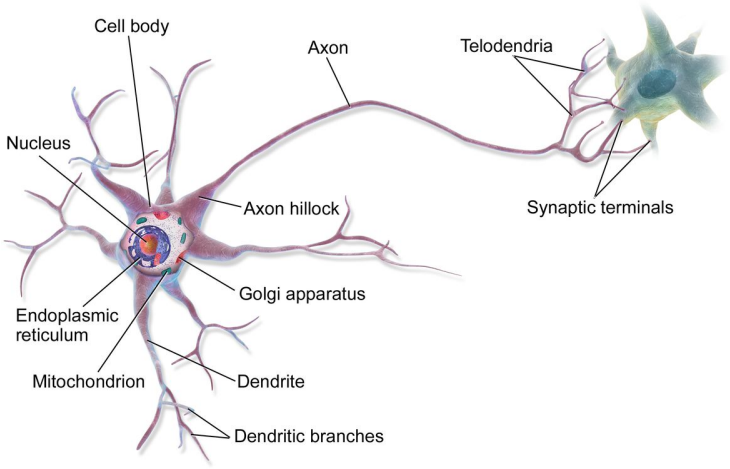
V.S.



Credit: knime.com

Input → $f\left(b + \sum_{i=1}^{n} x_i w_i\right)$ → Output

Biological neuron v.s. artificial neuron (perceptron)?



Credit: Wiki

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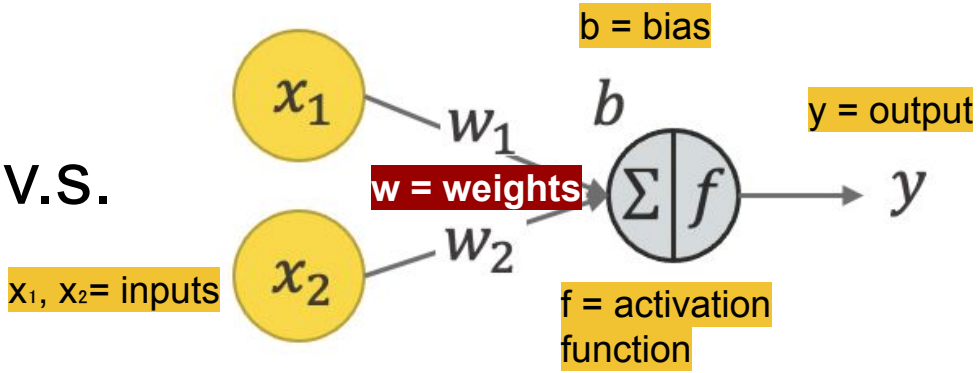


Credit: knime.com

Input → $f\left(b + \sum_{i=1}^{n} x_i w_i\right)$ → Output

"Neurons that fire together, wire together."

- Donald Hebb -

My second home!

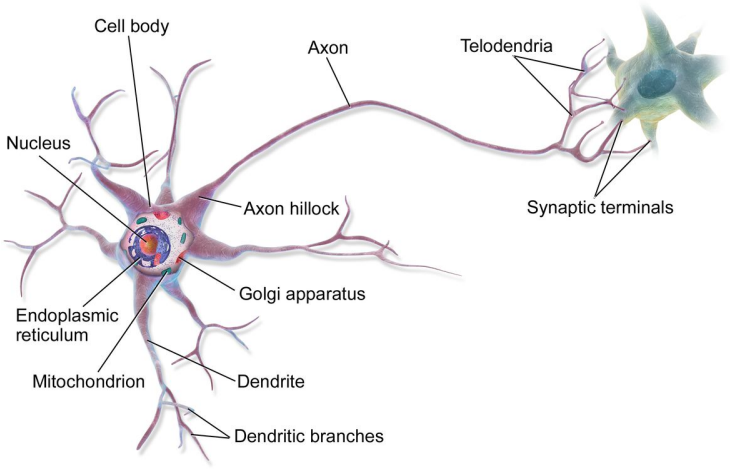
2 hr 9 min
97 miles

1 hr 56 min
74.9 miles

You are here!

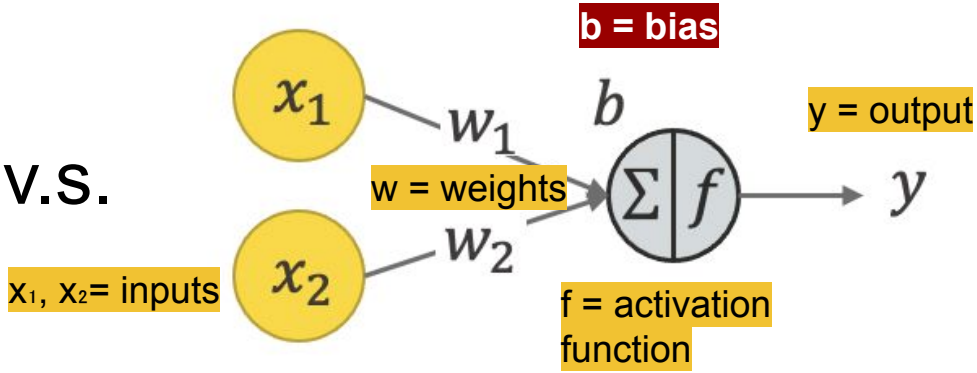
Google

Biological neuron v.s. artificial neuron (perceptron)?



Credit: Wiki

V.S.



Credit: knime.com

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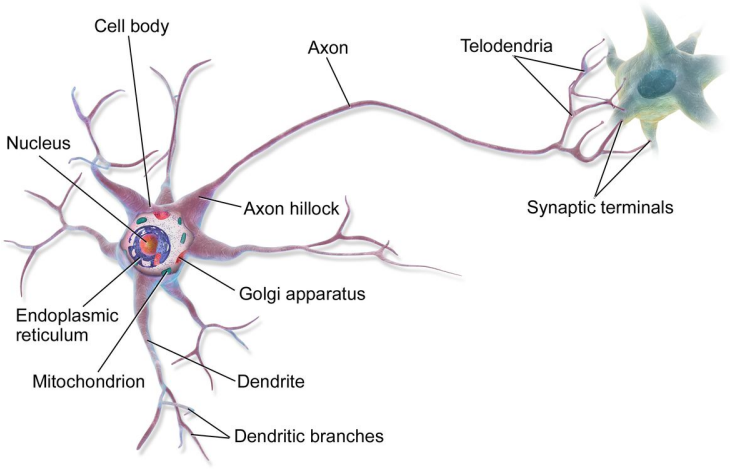
Biological neuron v.s. artificial neuron (perceptron)?



Credit: Wiki

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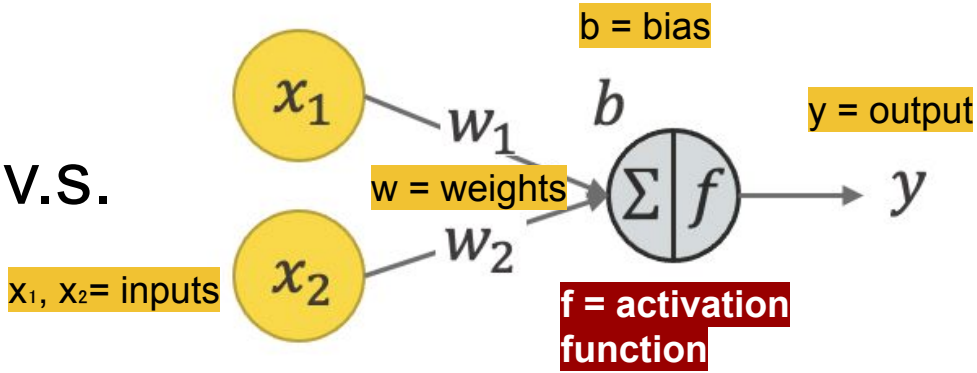

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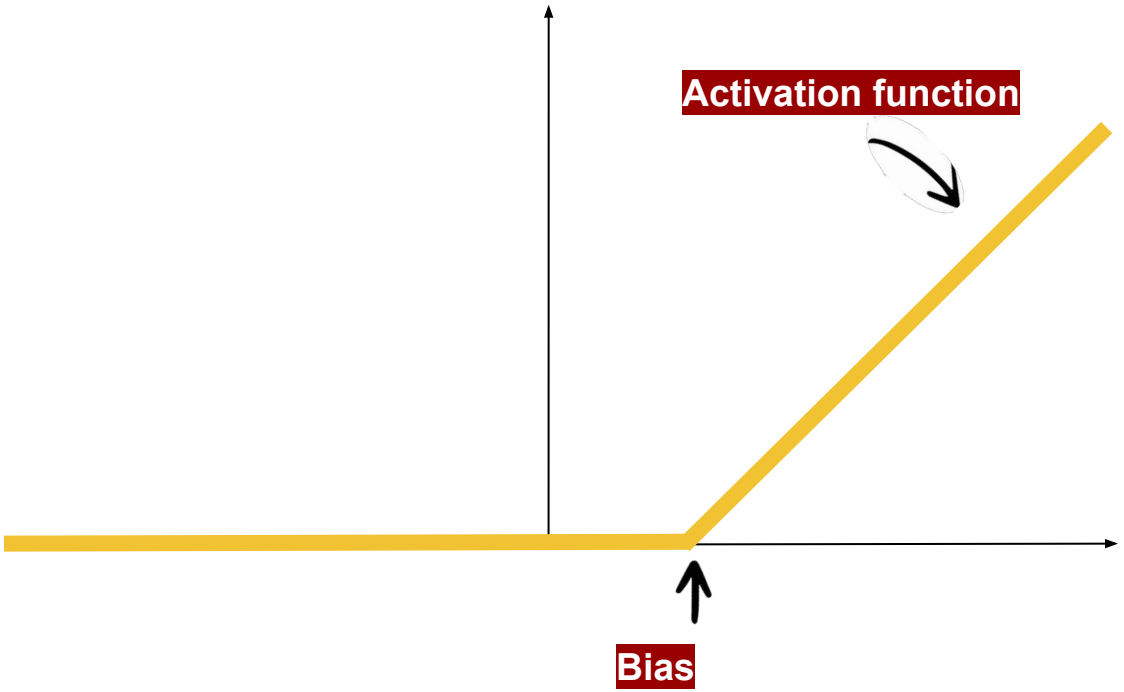
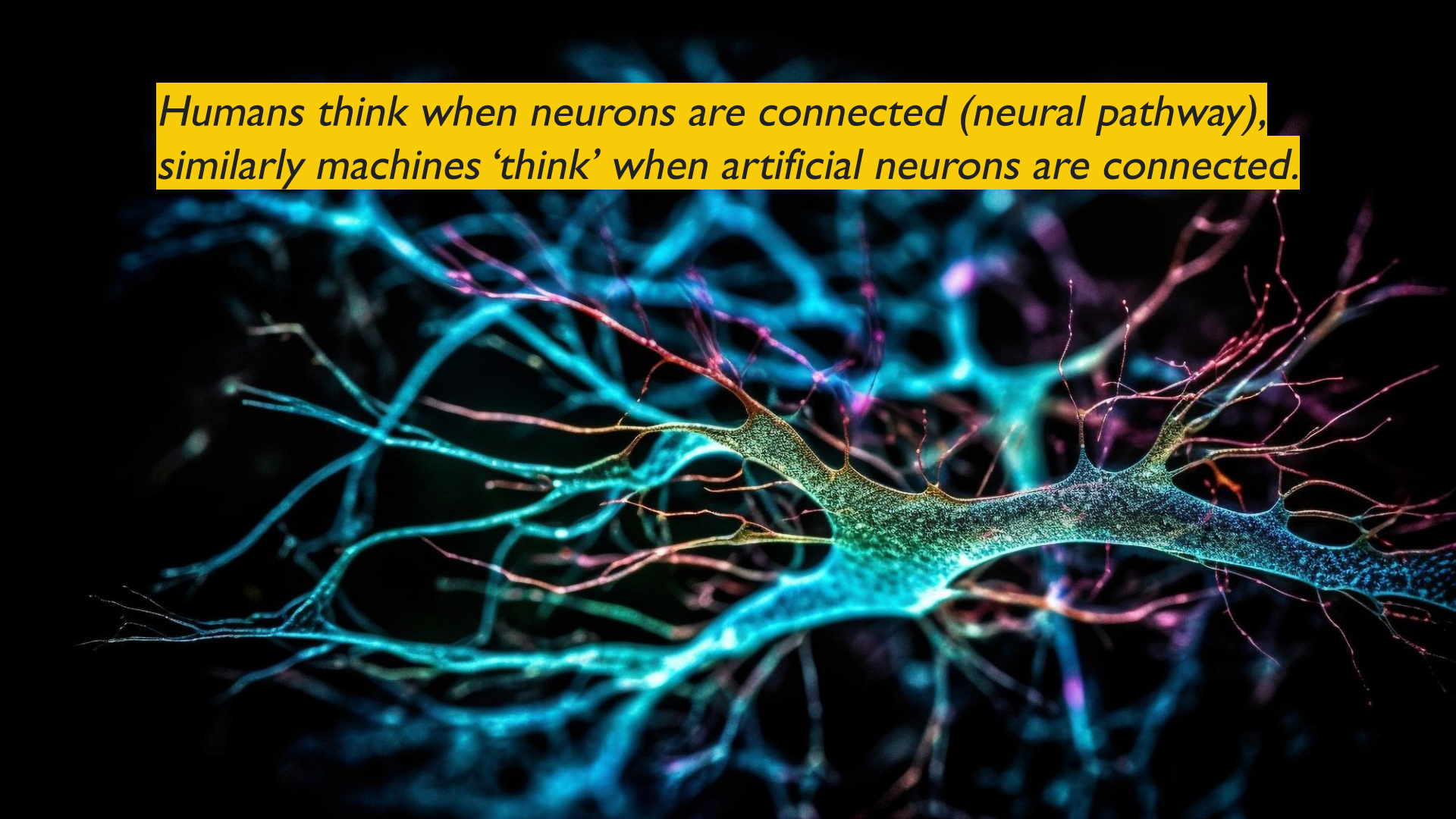
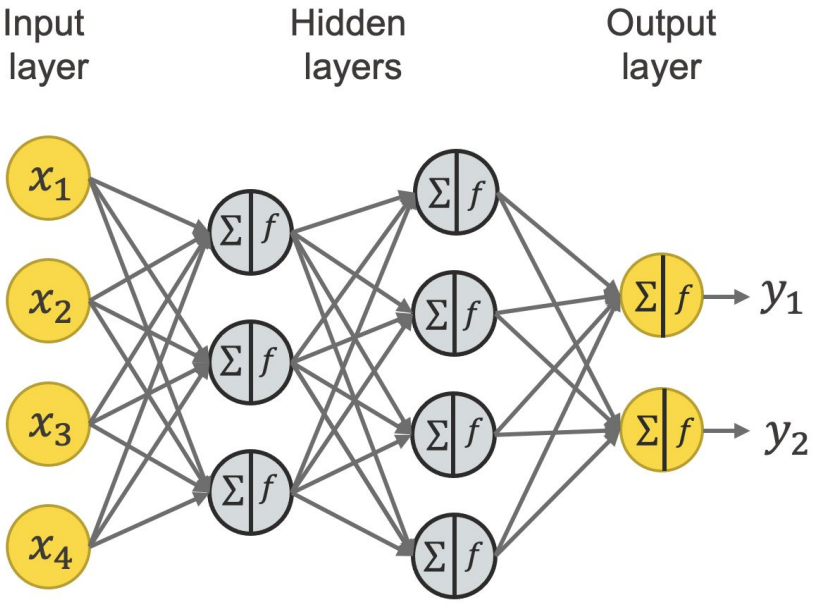
Biological neuron v.s. artificial neuron (perceptron)?



Humans think when neurons are connected (neural pathway), similarly machines 'think' when artificial neurons are connected.



Neural networks are one way that a machine 'thinks' and 'learns'...



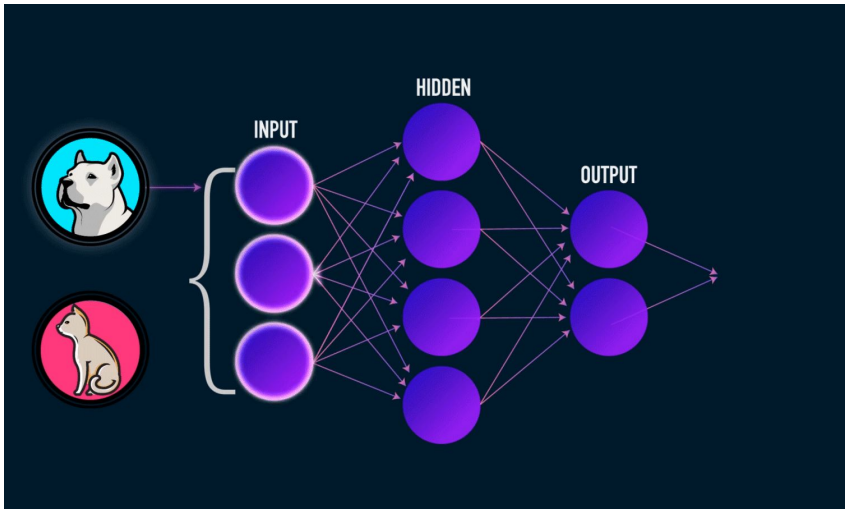
Credit: knime.com

YOU v.s. MACHINE

Dog

Cat

YOU v.s. MACHINE



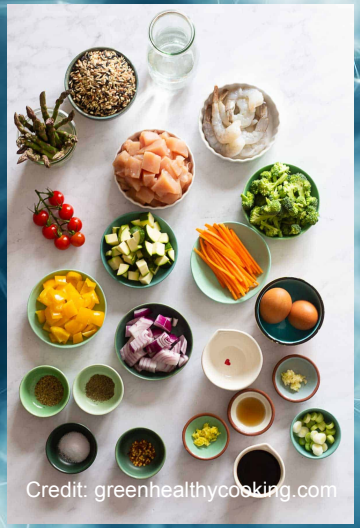
Credit: upadhyay-shivam.medium.com

What is Machine Learning?

The machine learns the pattern rather than you explicitly telling the machine the pattern

Credit: thedigitaldoctorate.com

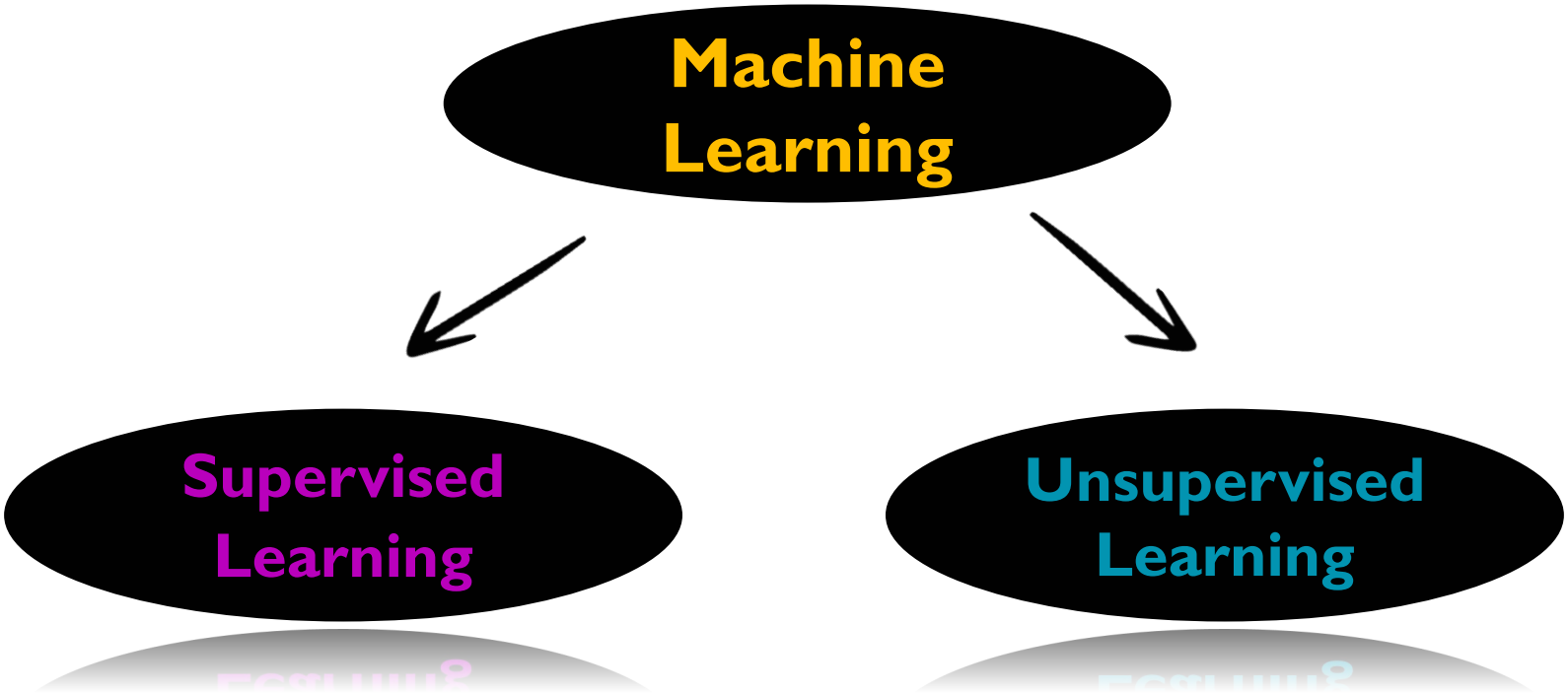
v.s.


Credit: greenhealthycooking.com

Humans learn in different ways…

…so do **machines.**

Image Credits: Freepik



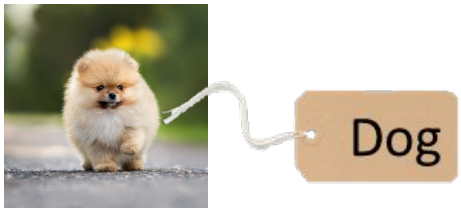
Supervised learning you tell the computer what to learn (i.e. a cat or dog) while unsupervised learning you don’t tell the computer what to learn.

V.S.
Supervised learning is when you give the computer the ingredients and final dish, then tell it to find a recipe.
Unsupervised learning is when you give the computer the ingredients and ask it to create a recipe and new dish.
Image Credit: jcomp on Freepik
Image Credit: Freepik

Let’s use a classification task to explain this…

Image Credit: thabisfotowelt, Pixabay
Image Credit: GreenCross Vets

Supervised Learning

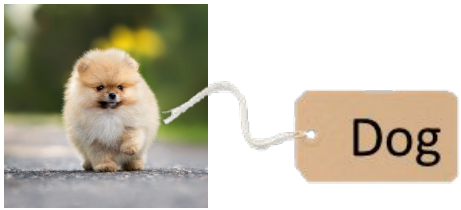


Labelled Data

Unsupervised Learning

Image Credit: thabisfotowelt, Pixabay
Image Credit: GreenCross Vets

Supervised Learning



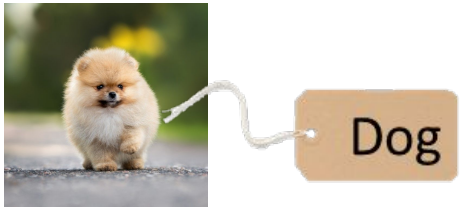
Labelled Data

Unsupervised Learning

Unlabelled Data

Image Credit: thabisfotowelt, Pixabay
Image Credit: GreenCross Vets

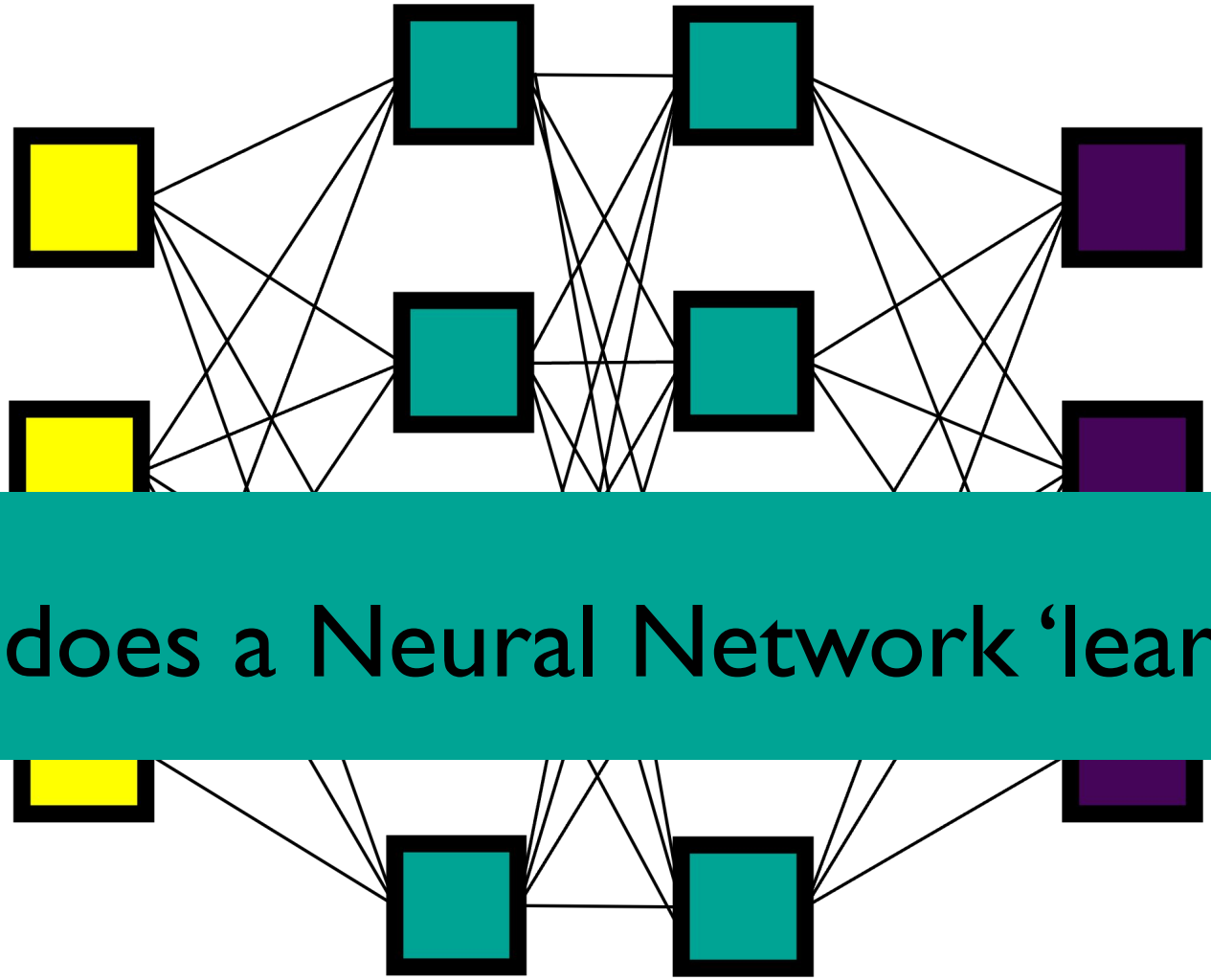
NEURAL NETWORKS



Labelled Data

Unlabelled Data

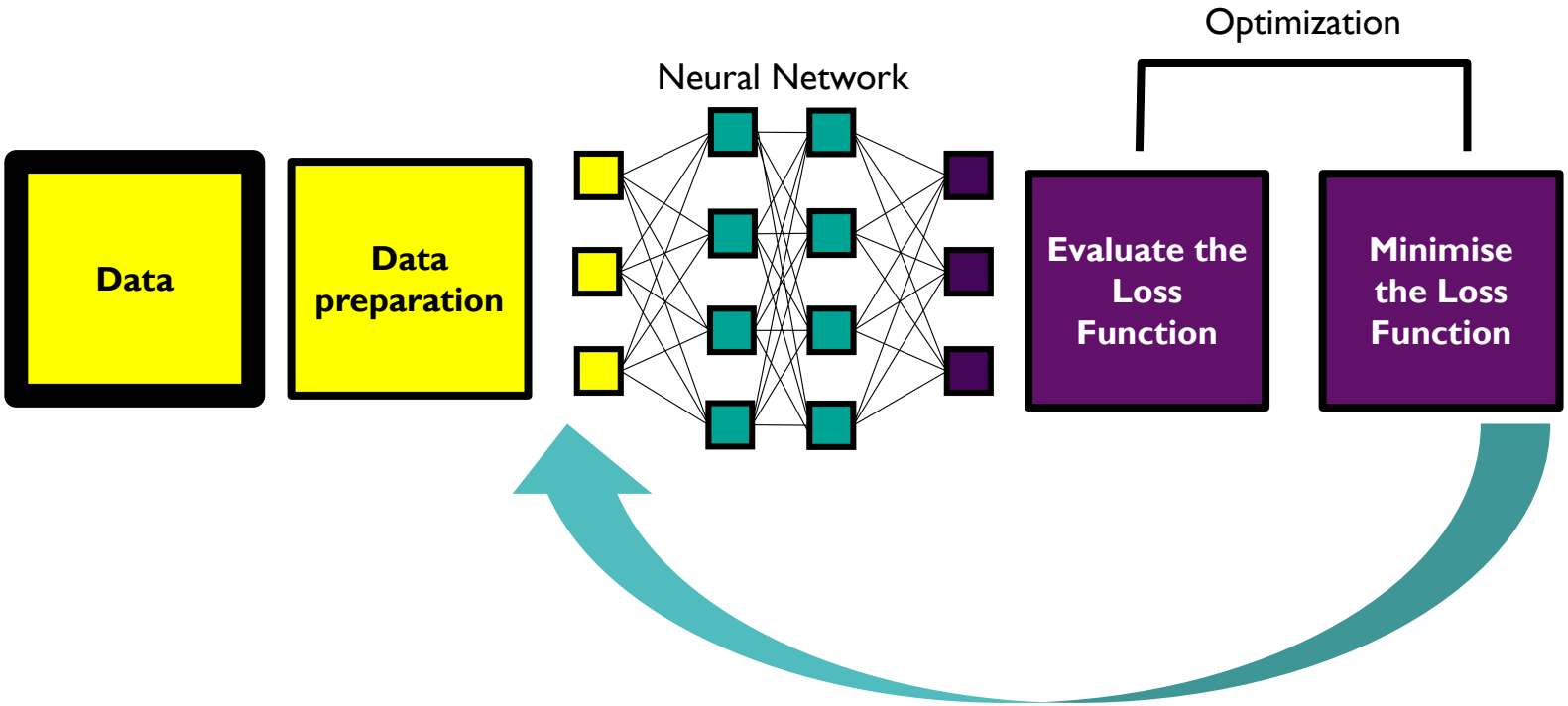
Image by senivpetro on Freepik

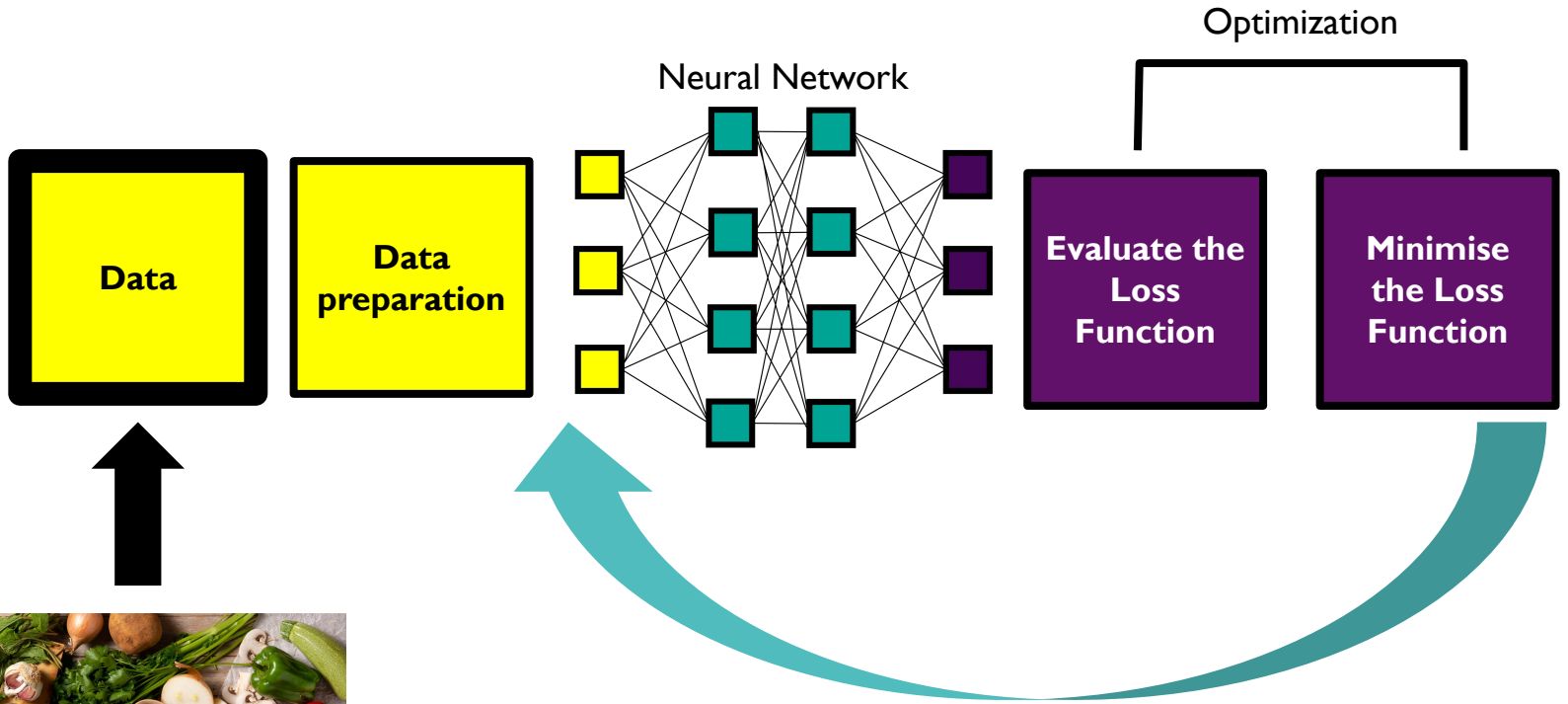


How does a Neural Network ‘learn’?

\\ Like humans, neural networks learn by their mistakes…

…but we call it ‘Optimization’!


Optimization
Neural Network
Data
Data preparation
Evaluate the Loss Function
Minimise the Loss Function



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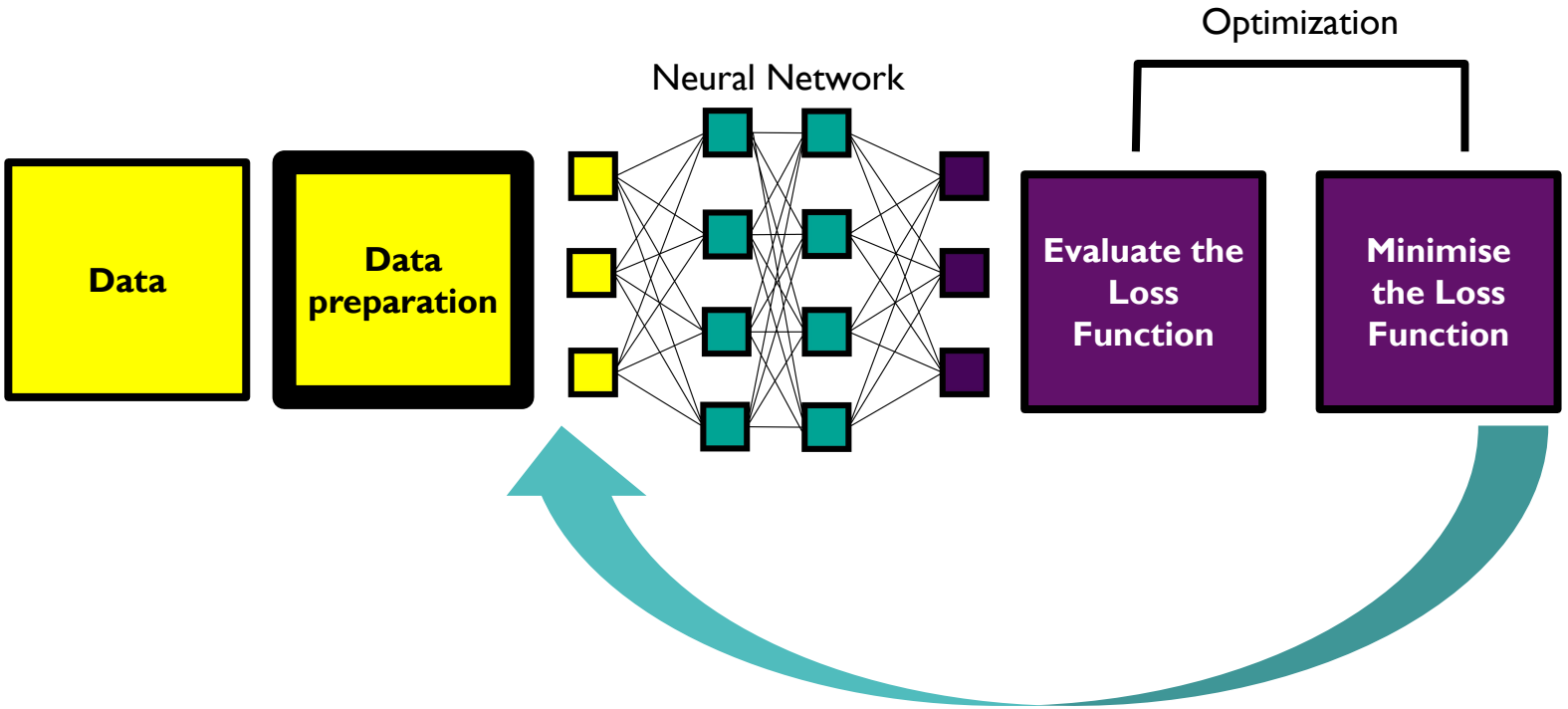
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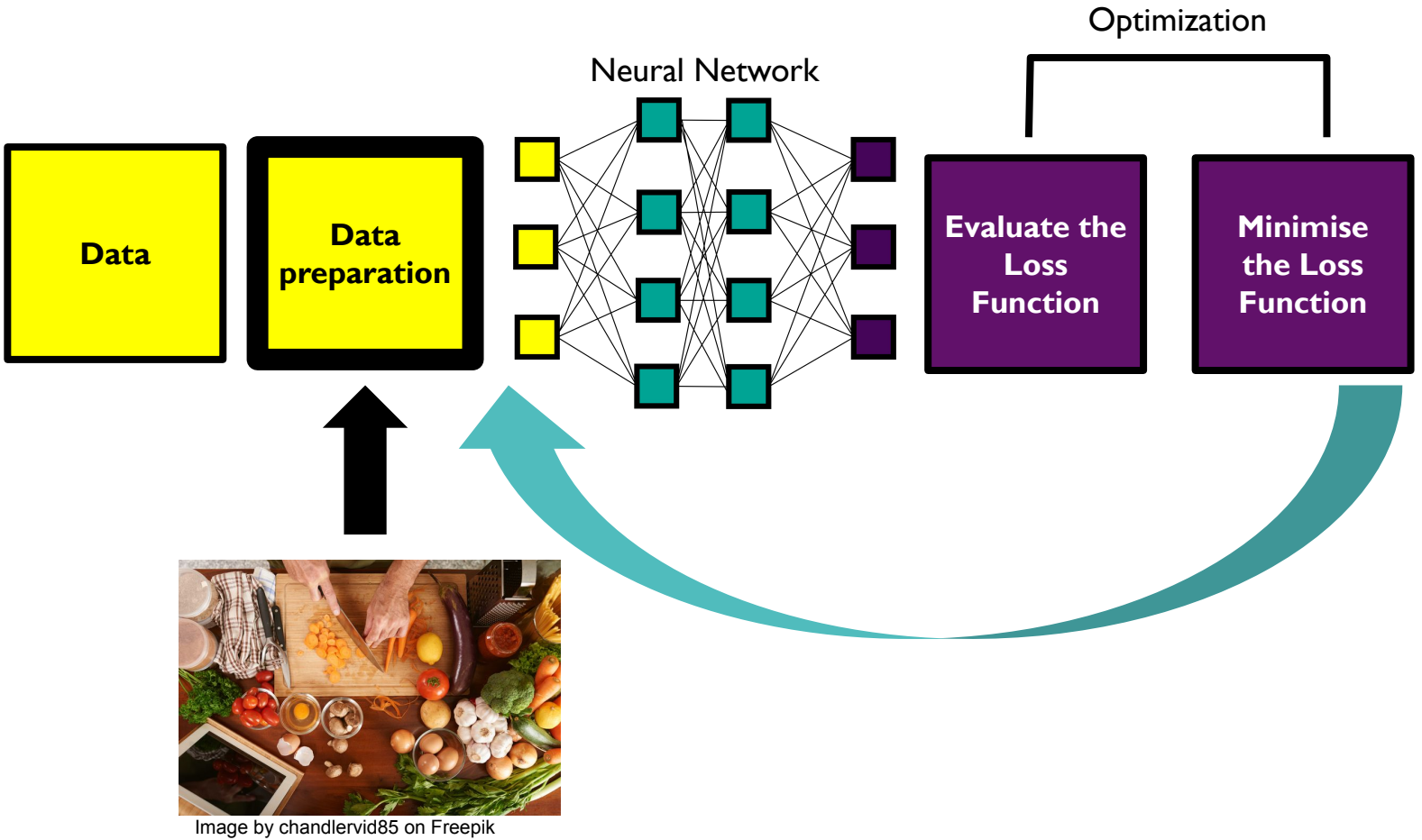
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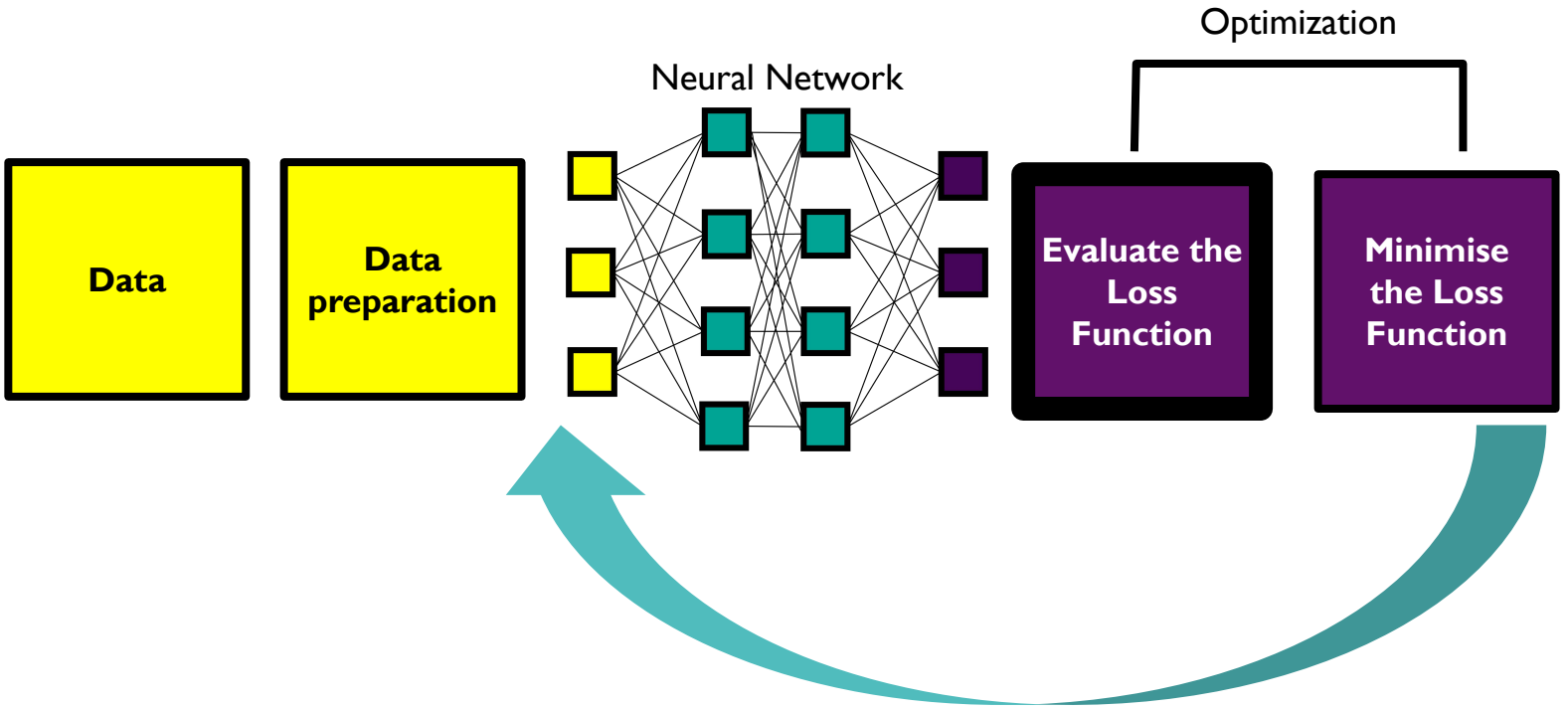
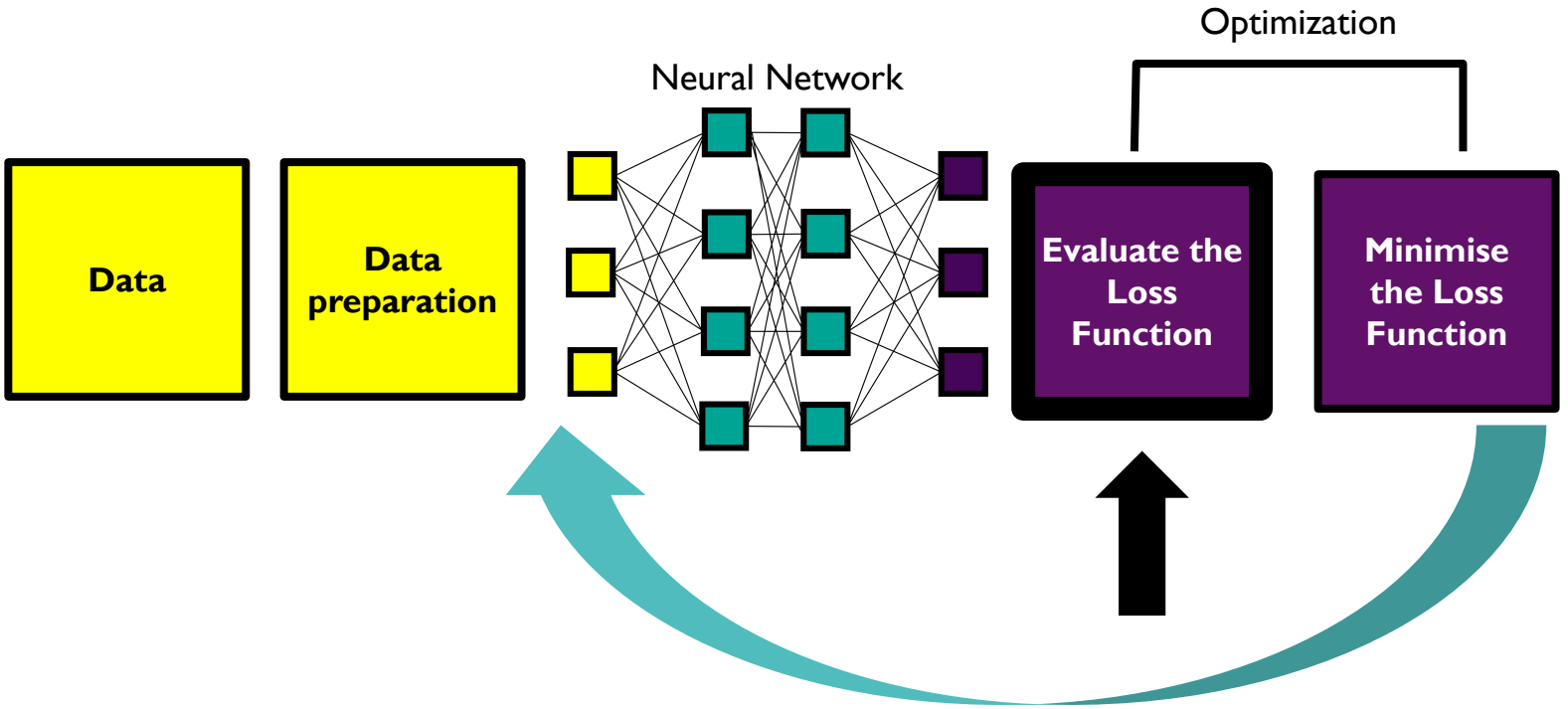
Image by chandlervid85 on Freepik



*"The **Loss Function** is the choice of the error function which is how the optimization algorithm is told how good the model is…"*

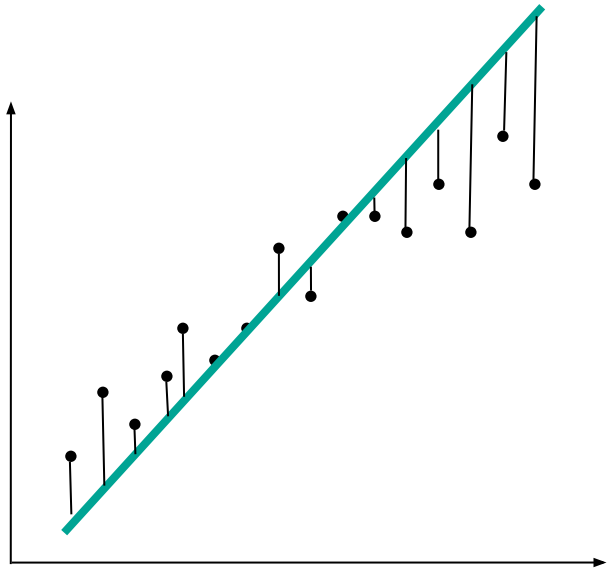


*"The **Loss Function** is the choice of the error function which is how the optimization algorithm is told how good the model is…"*

Optimization: Loss Function

“As a machine learning engineer, it is your responsibility to chose the loss function that best suits your problem.”

For example:



Optimization: Loss Function

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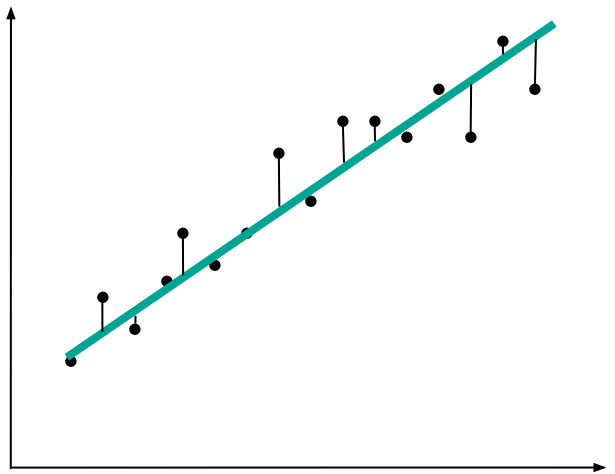


Optimization: Loss Function

"As a machine learning engineer, it is your responsibility to chose the loss function that best suits your problem."

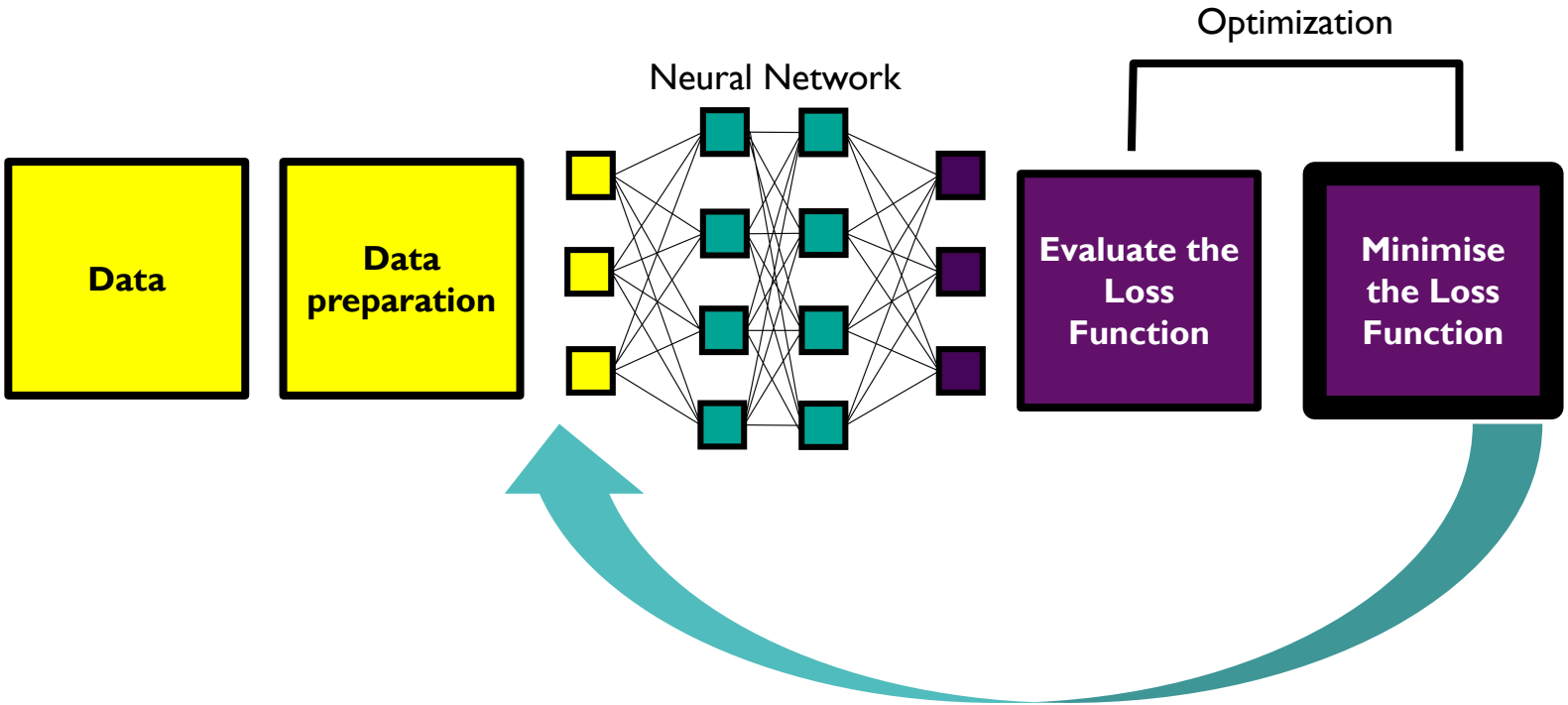
For example:

1) Mean Squared Error (MSE)
2) Mean Squared Logarithmic Error (MSLE)
3) Mean Absolute Error (MAE)

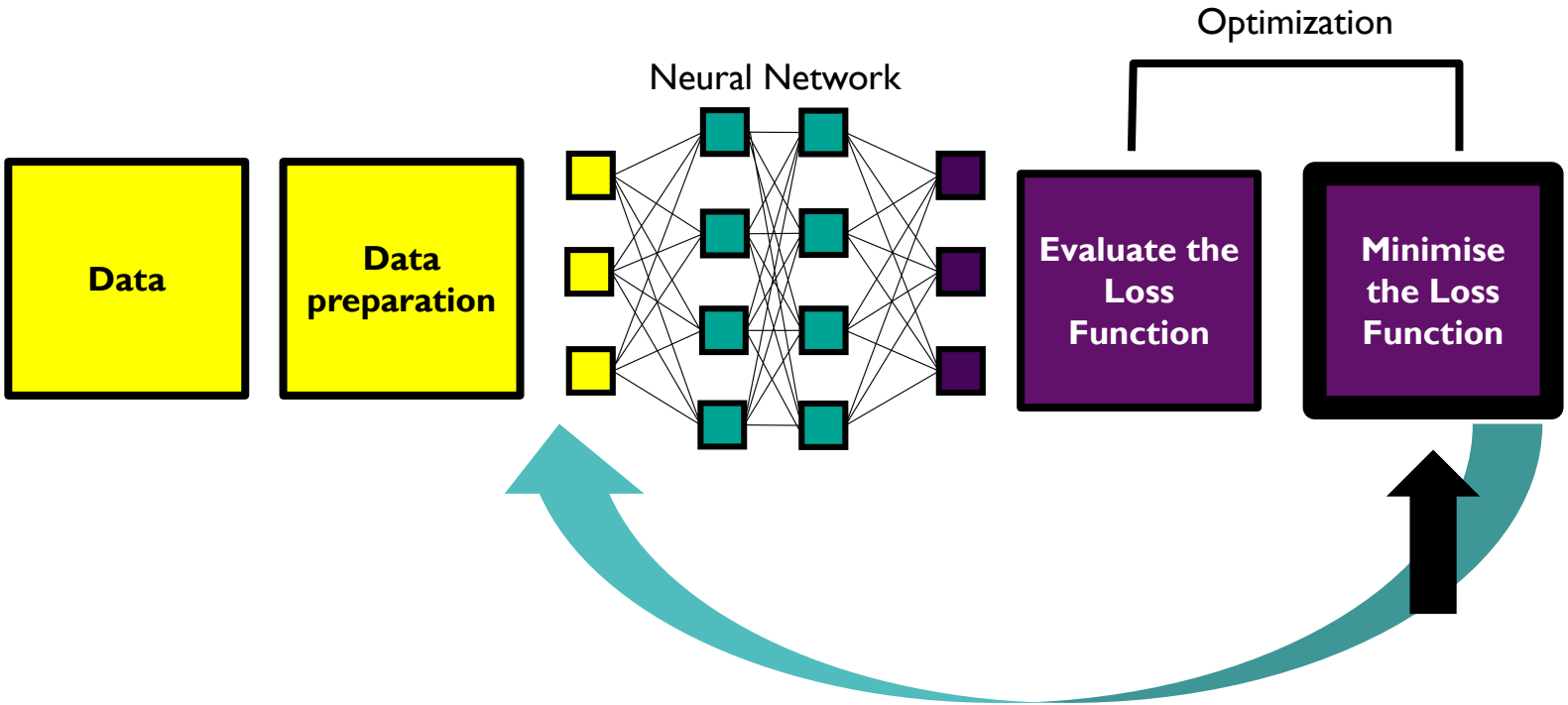
$$MSE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}$$

$$MSLE = \frac{1}{n}\sum_{i=1}^{n}(\log(Y_i) - \log(\hat{Y}_i))^2$$

$$MAE = \frac{1}{n}\sum_{j=1}^{n}|y_j - \hat{y}_j|$$



*"...**Optimizers** are responsible for changing the weights, bias and learning rate of the neurons in the neural network to reach the minimum loss function."*



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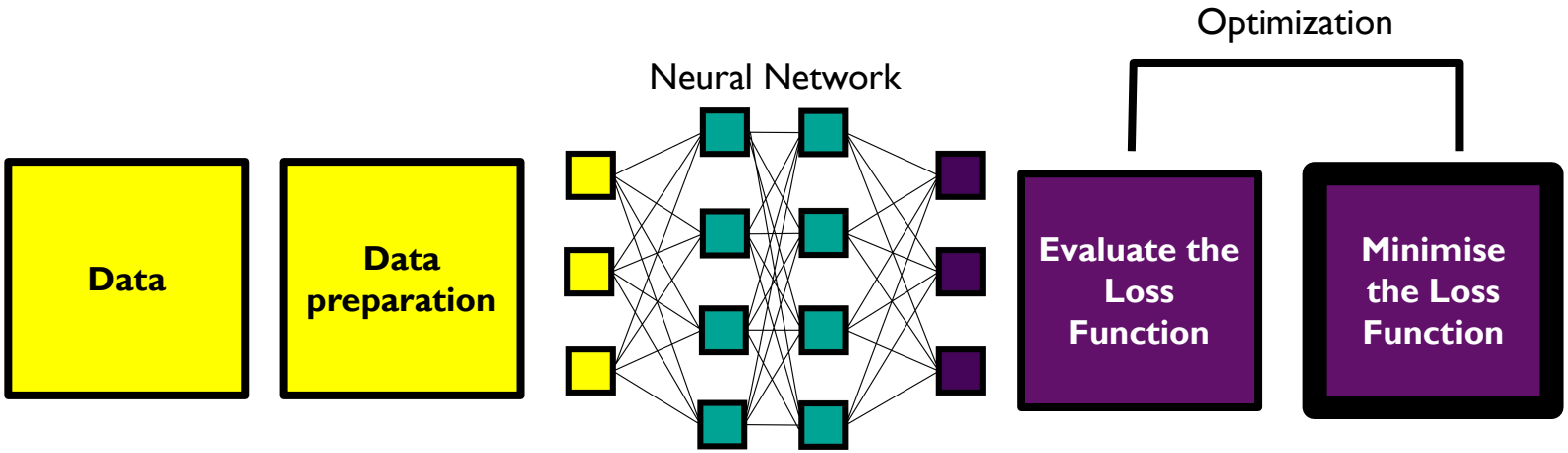


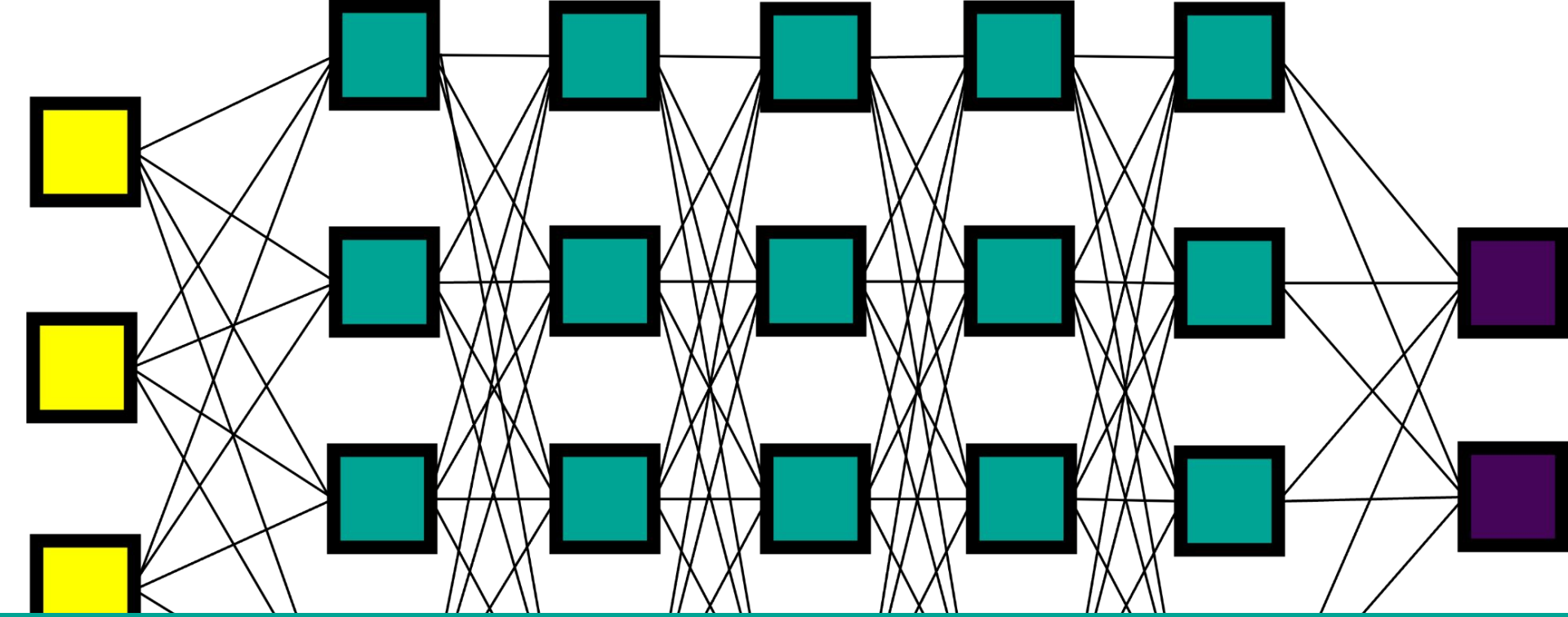
New weights and bias

Learning Rate

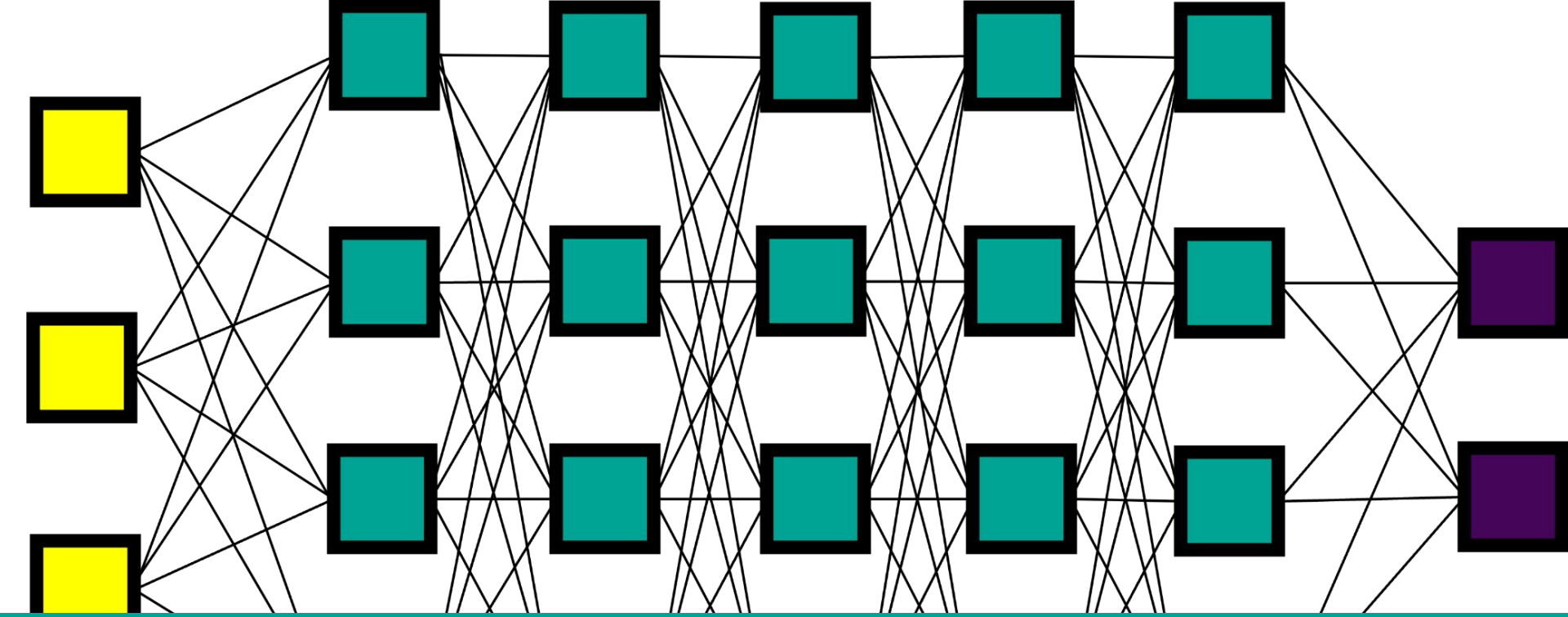
Loss Function

$$\theta_t = \theta_{t-1} - \alpha_t \nabla_{\theta_{t-1}} L_t$$

Current weights and bias

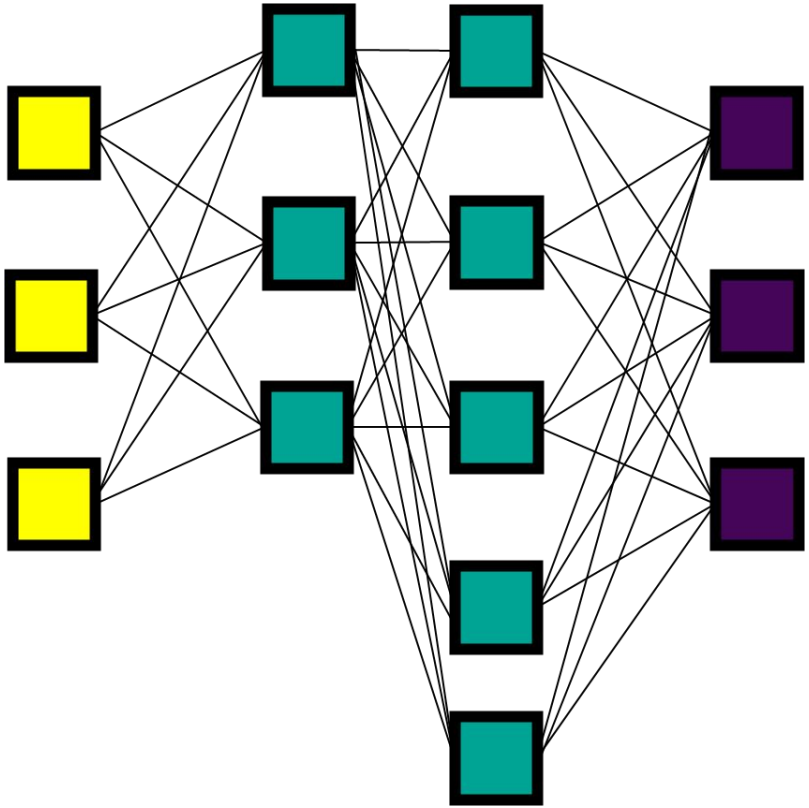


In order for the neural network to learn the neural network architecture may need to be adjusted…

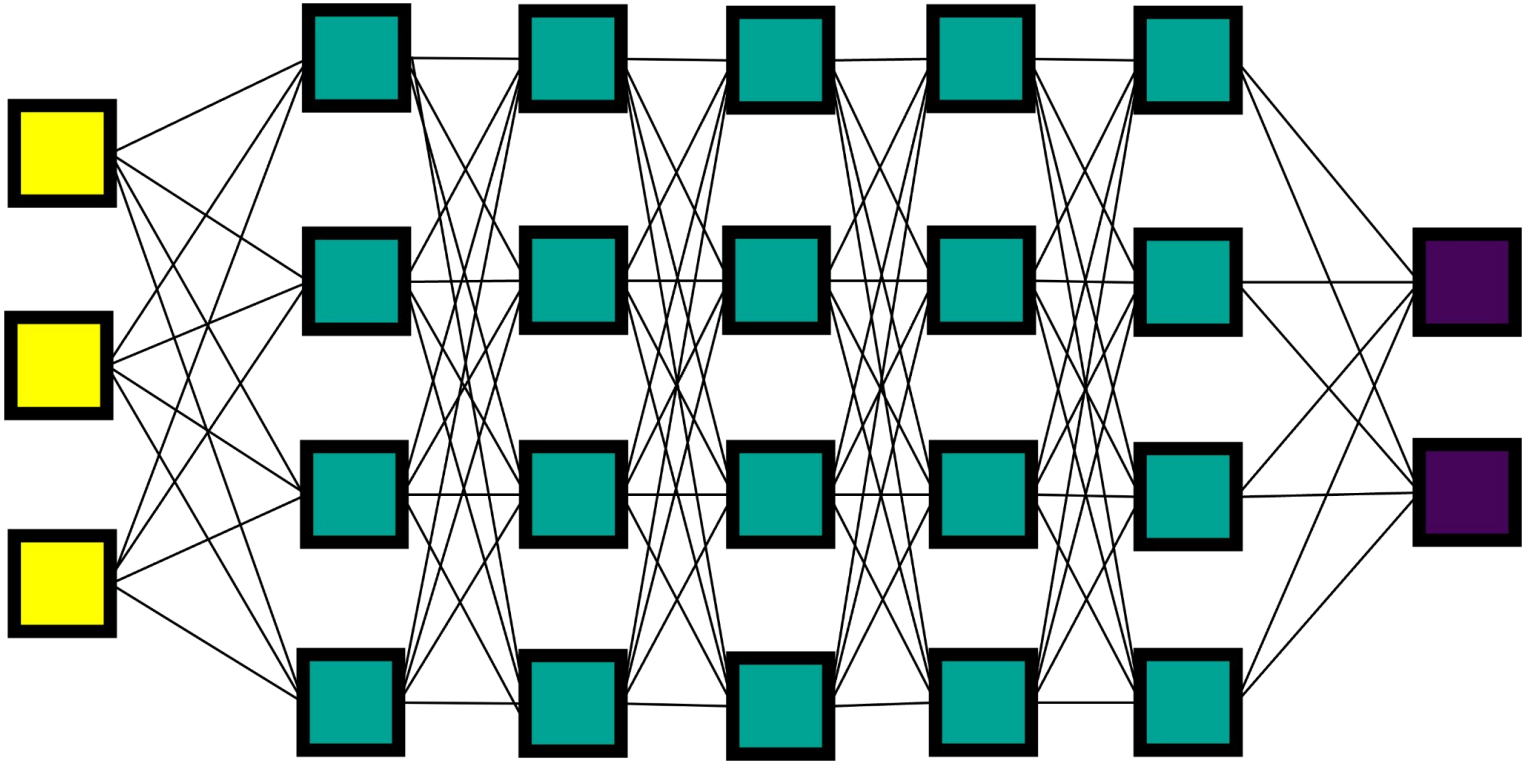


… it is up to a machine learning engineer to adjust the neural network architecture so that the machine ‘learns’.

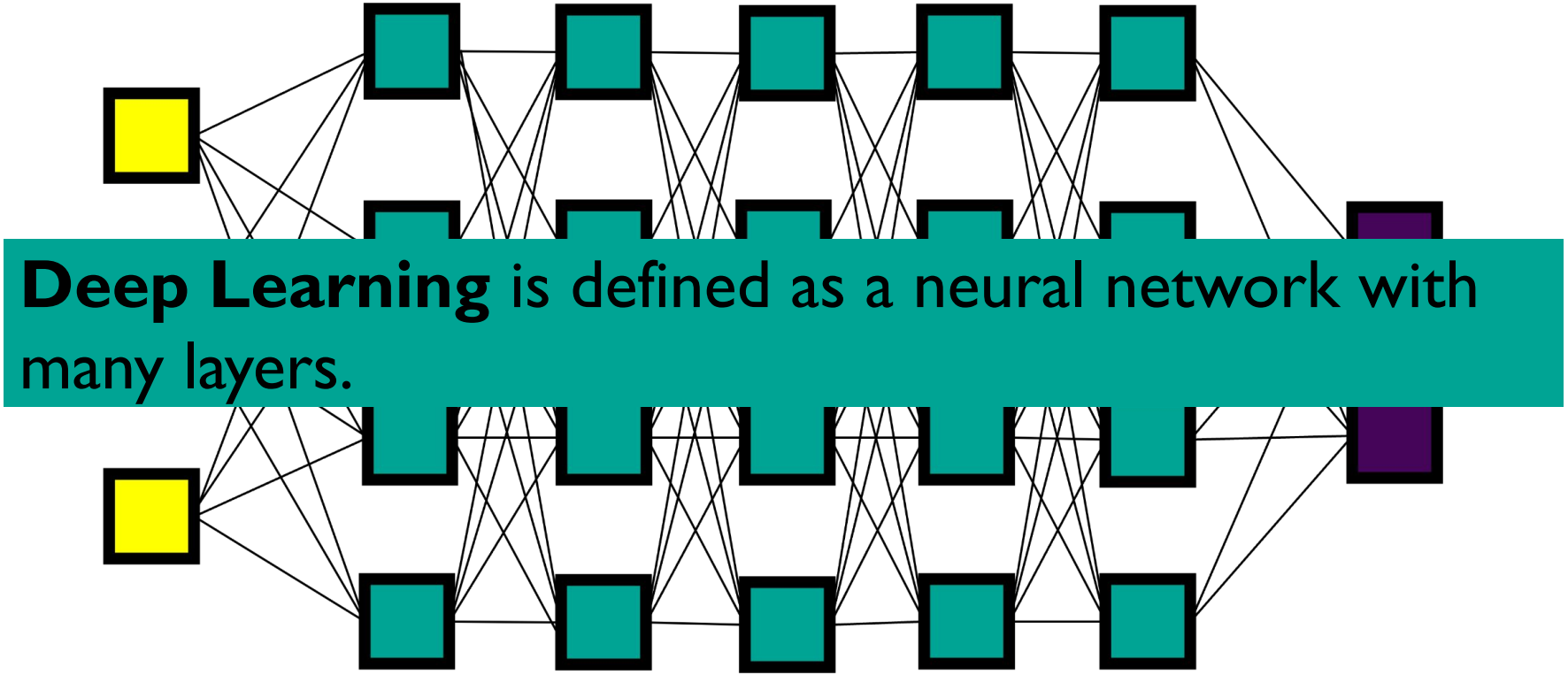
E.g. vary the width of the neural network…



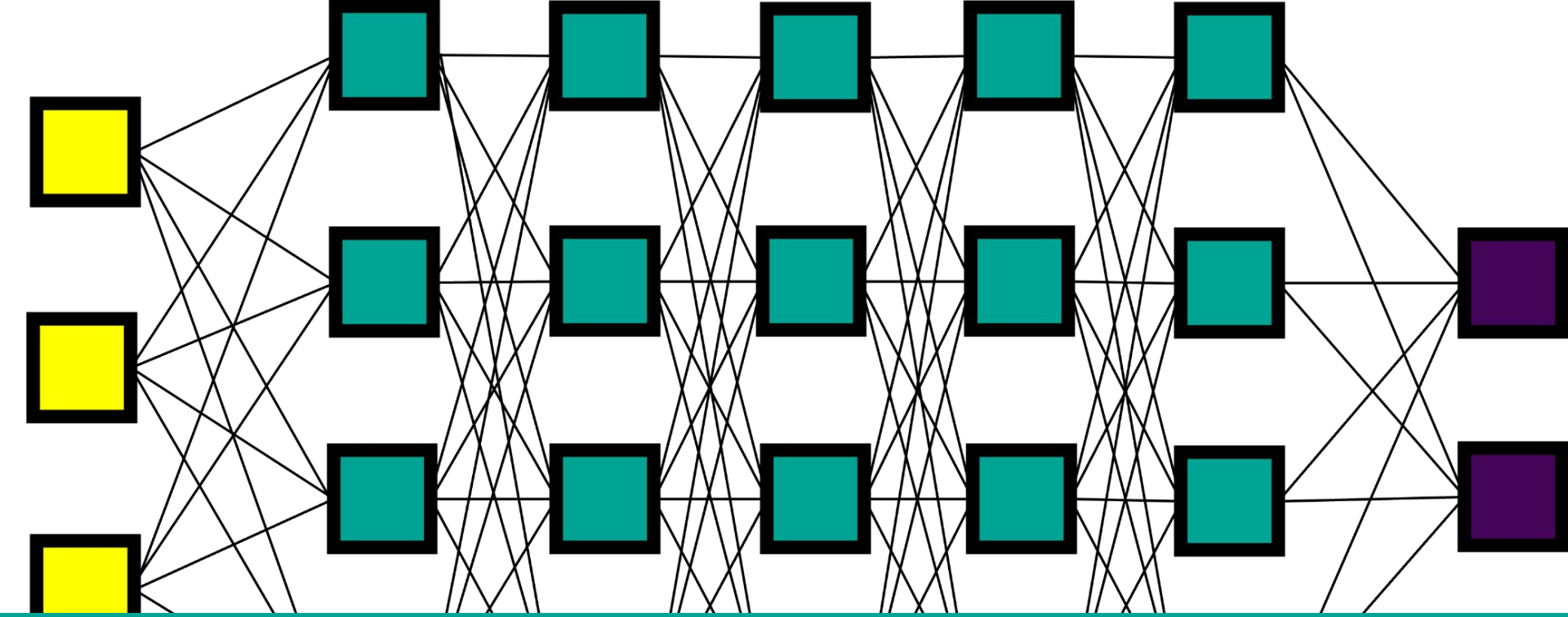
E.g. vary the depth of the neural network…



Vary the depth of the neural network…



Deep Learning is defined as a neural network with many layers.



Different neural network architectures enable the machine to ‘learn’ different data types.

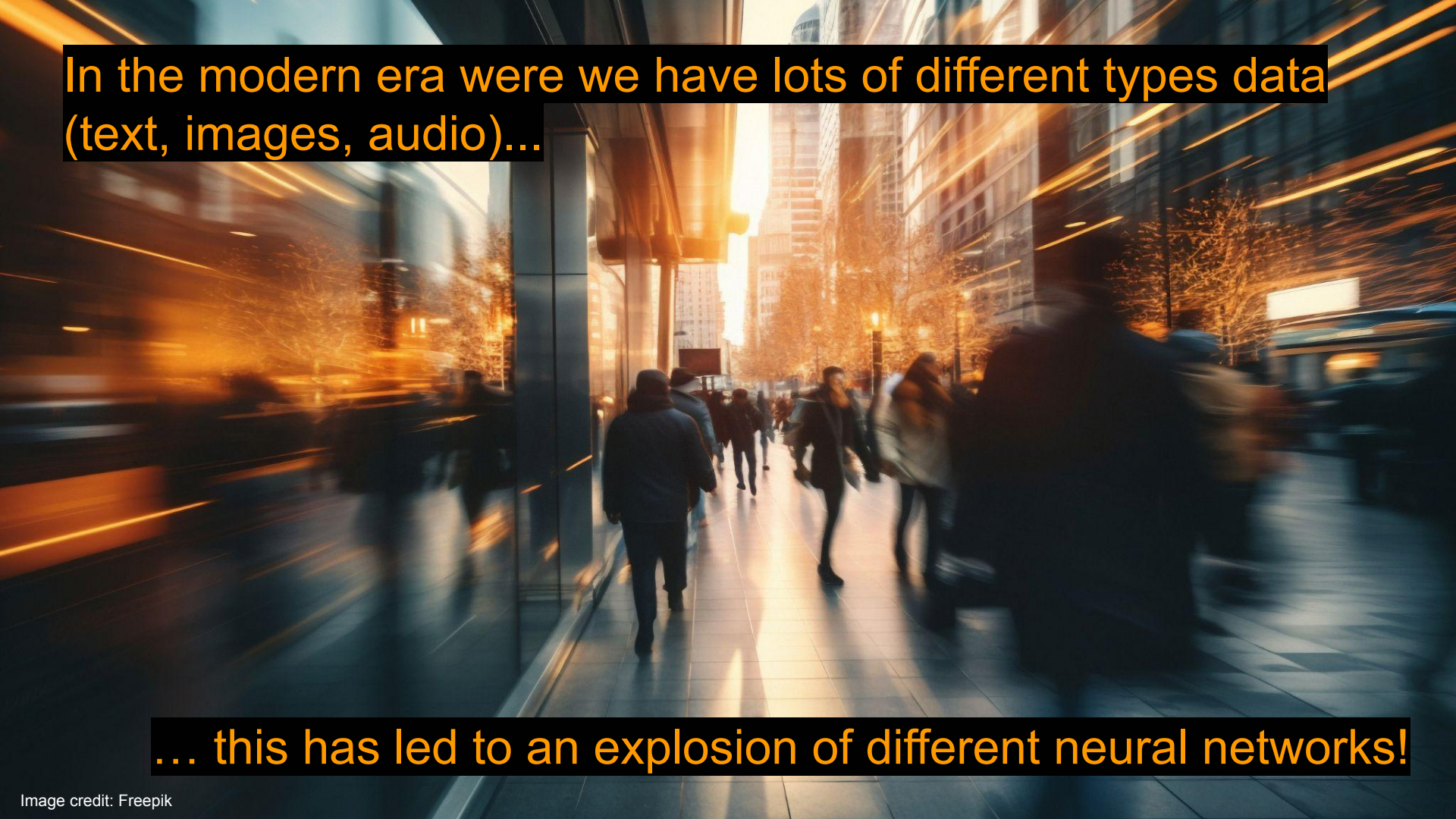
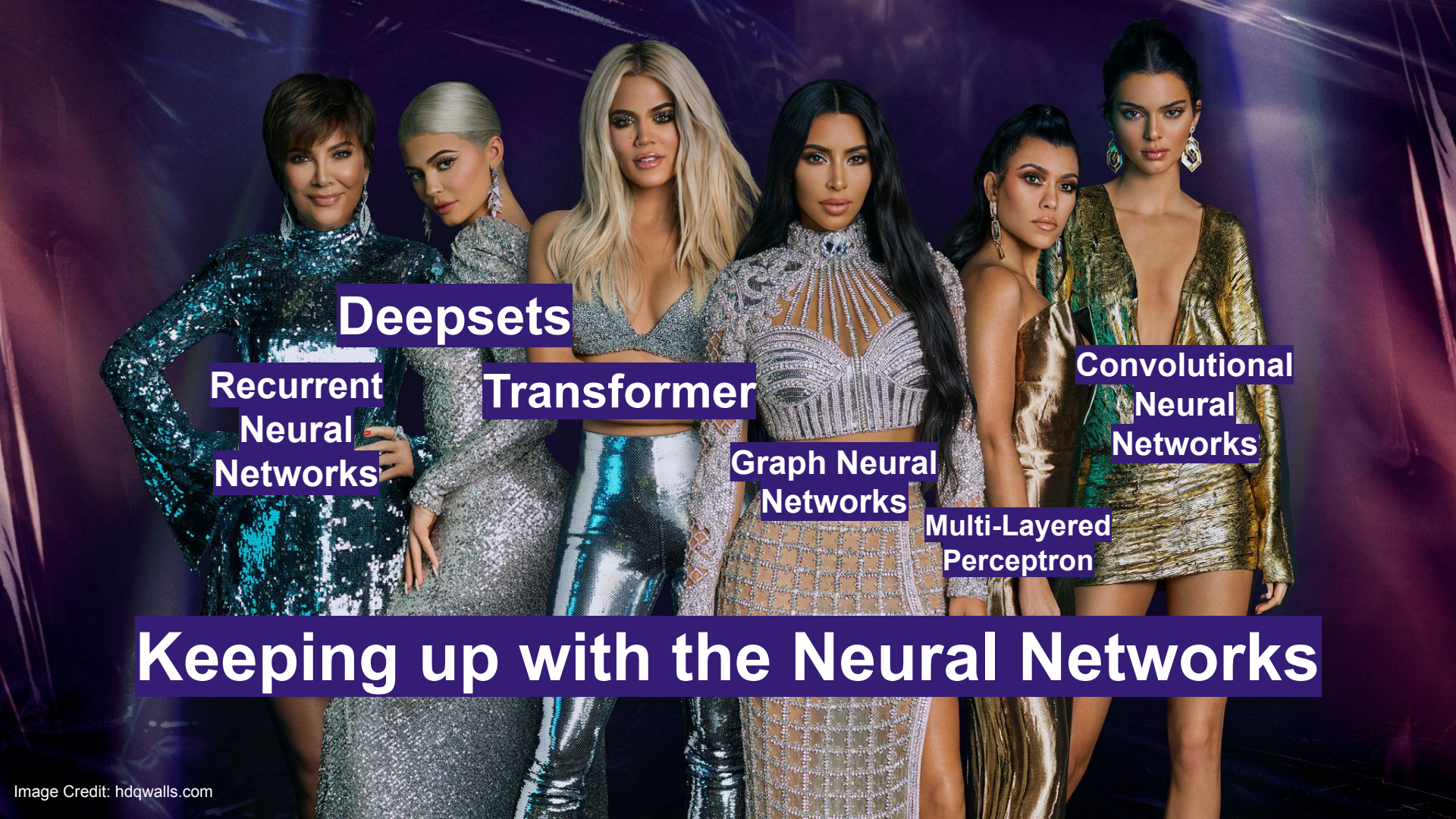
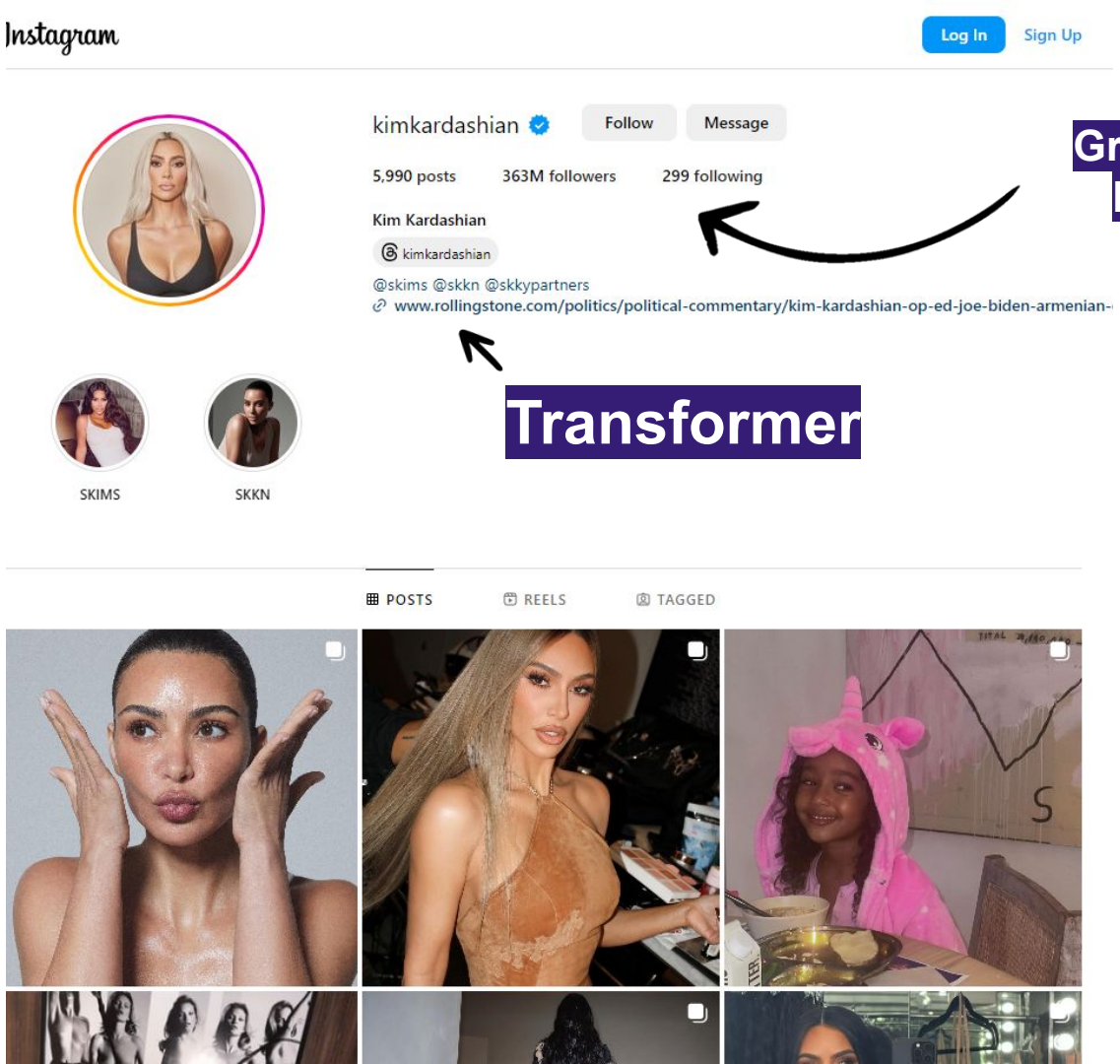


Image credit: Freepik


Deepsets
Recurrent Neural Networks
Transformer
Graph Neural Networks
Multi-Layered Perceptron
Convolutional Neural Networks
Keeping up with the Neural Networks
Image Credit: hdqwalls.com



Graph Neural Networks

Transformer

Convolutional Neural Networks

Image Credit: Hulu

Convolutional Neural Networks

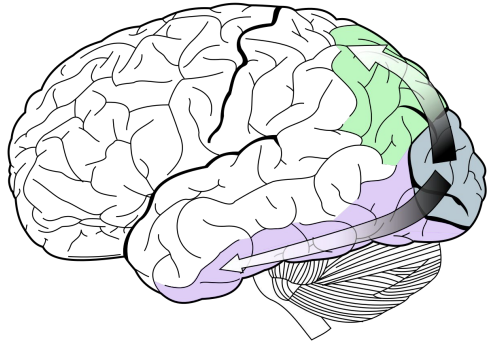
Image Credit: Antonello Trio/Getty images

Convolutional Neural Networks

It is an artificial neural network that features one or more convolutional layers

Image Credit: Antonello Trio/Getty images

How do **Humans** process **visual information**?



Dog

Image Credit: sheltieplanet.com and Selket (wiki)

Did you know that it takes your brain 100 milliseconds to process an image.

True or False?

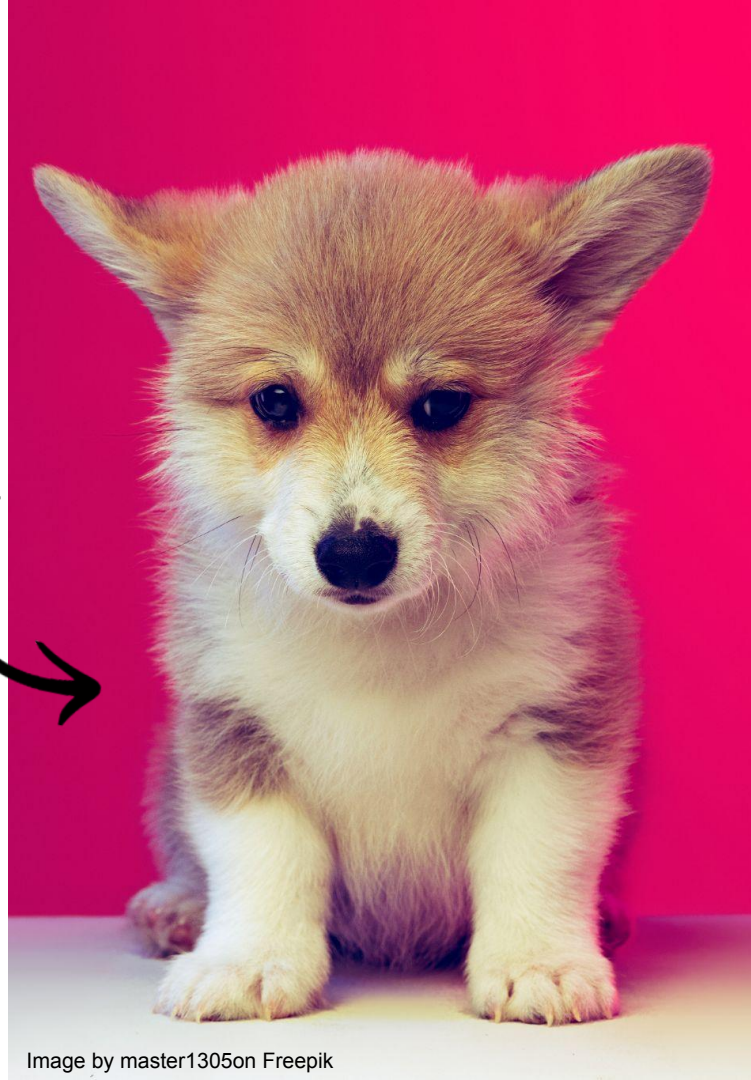


Image by master1305on Freepik

Did you know that it takes your brain 100 milliseconds to process an image.

False

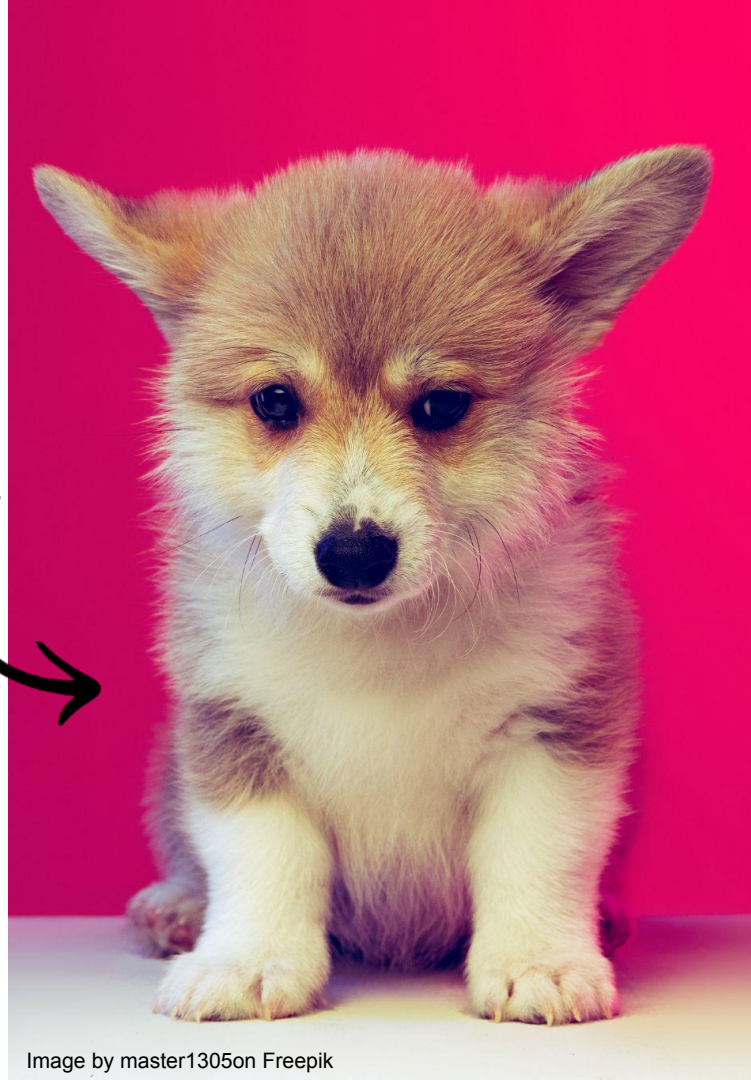


Image by master1305on Freepik

Did you know that it takes your brain 100 milliseconds to process an image.

False

“A team of neuroscientists from MIT has found that the human brain can process entire images that the eye sees for as little as 13 milliseconds”
- Anne Trafton

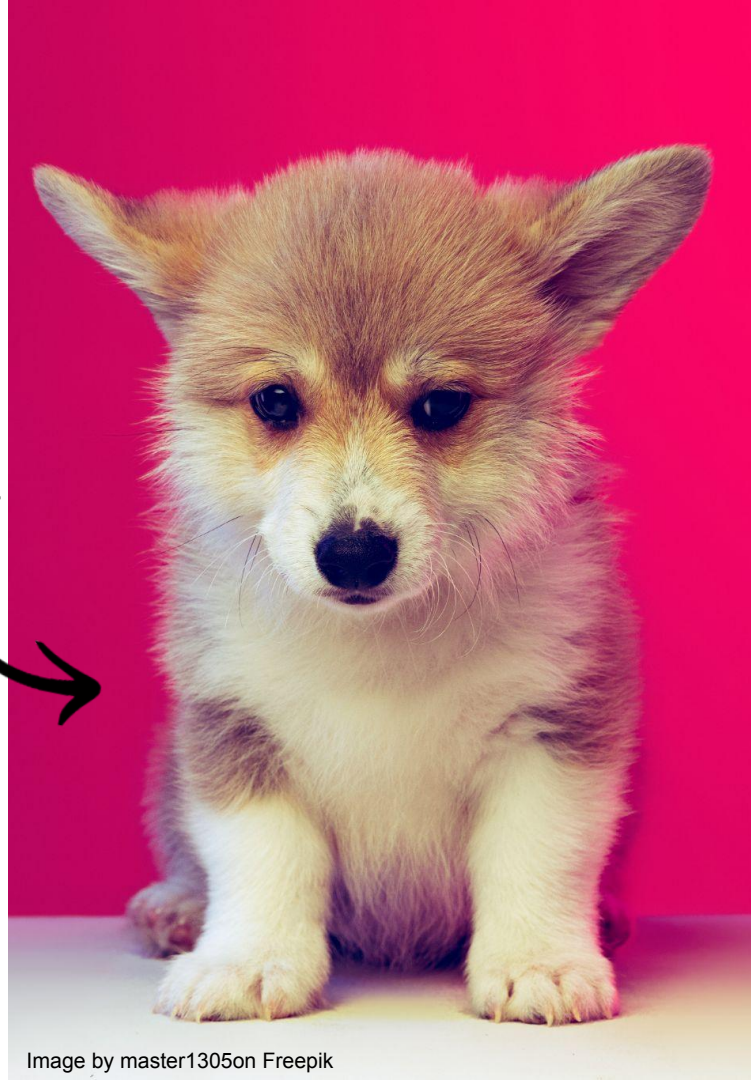
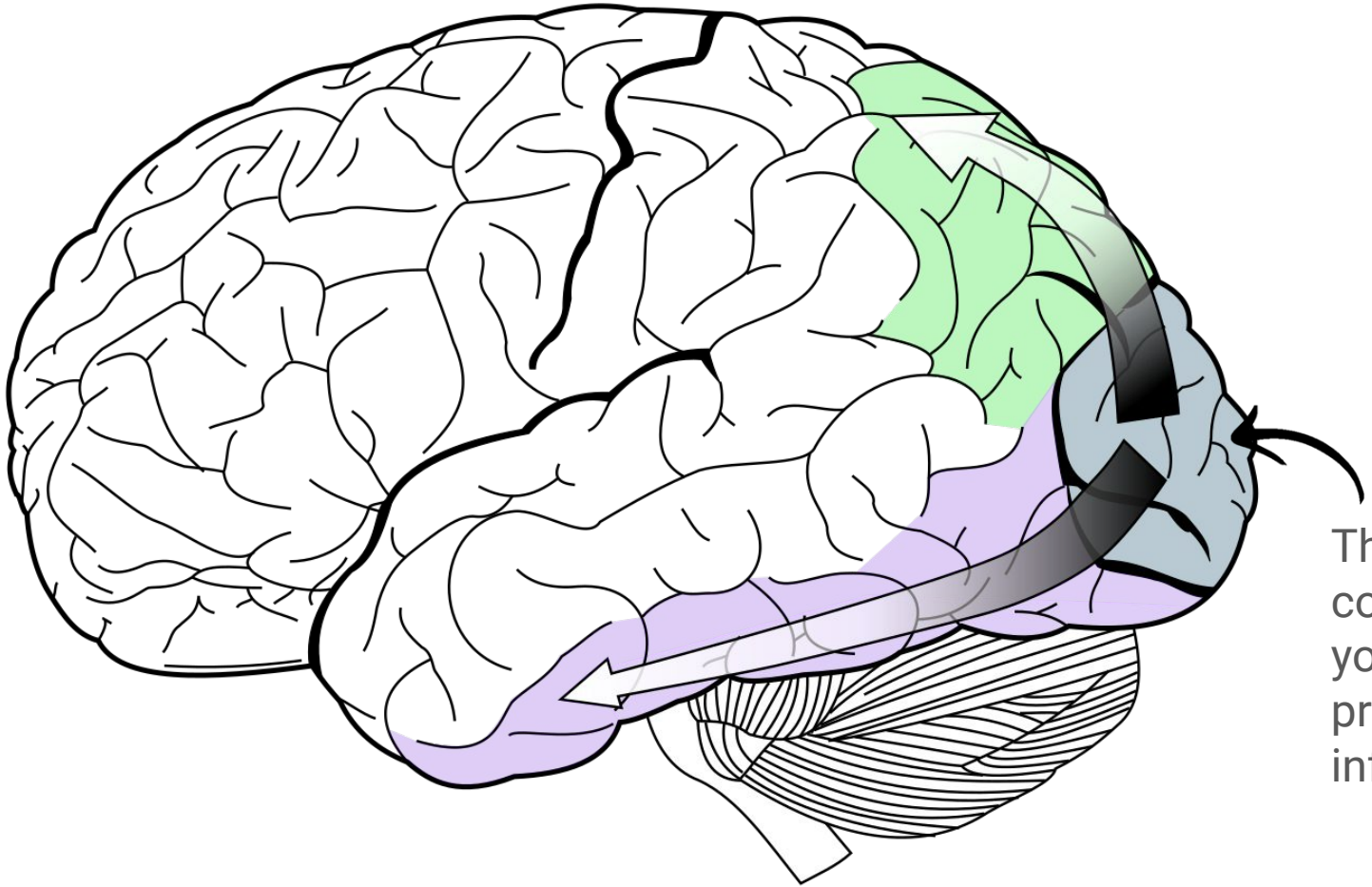


Image by master1305on Freepik

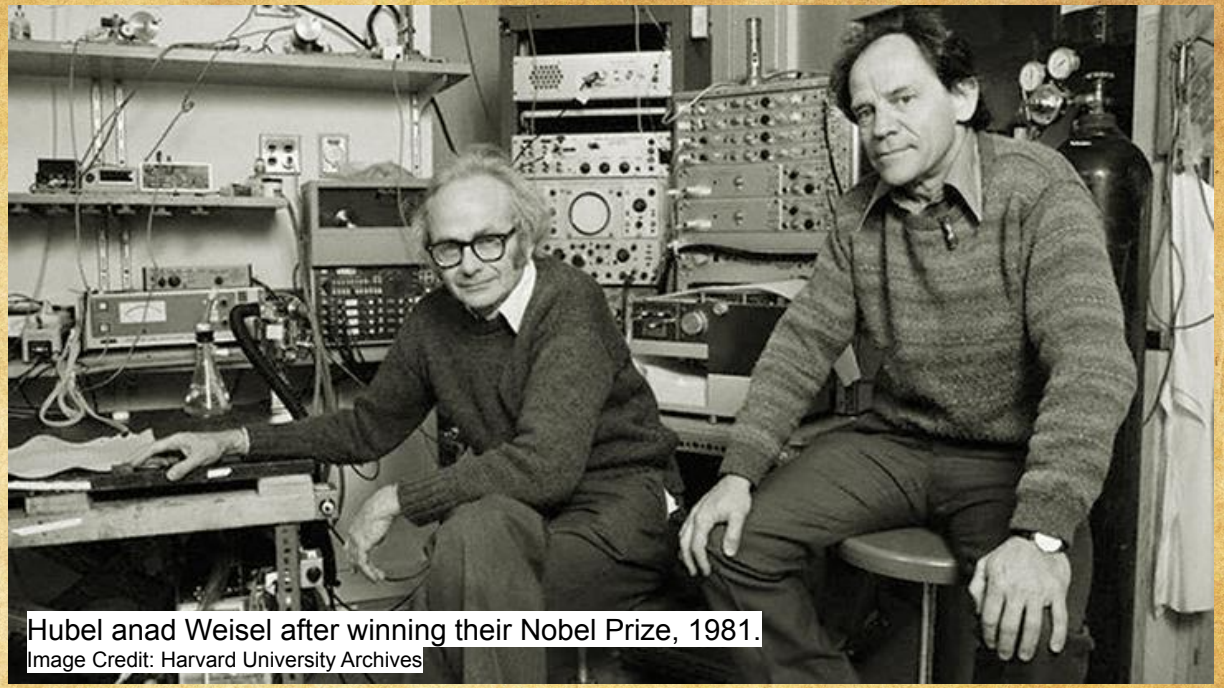


The visual cortex is where your brain processes visual information.

Image Credit: Selket (Wiki)

How do we know this?

Image Credit: wayhomestudio on Freepik



Hubel anad Weisel after winning their Nobel Prize, 1981.
Image Credit: Harvard University Archives

In the 1950s at Johns Hopkins University, the David Hubel and Torsten Wiesel performed pioneering research of how visual information is processed in the brains of mammals.

David and Torsten set up the following experiment…

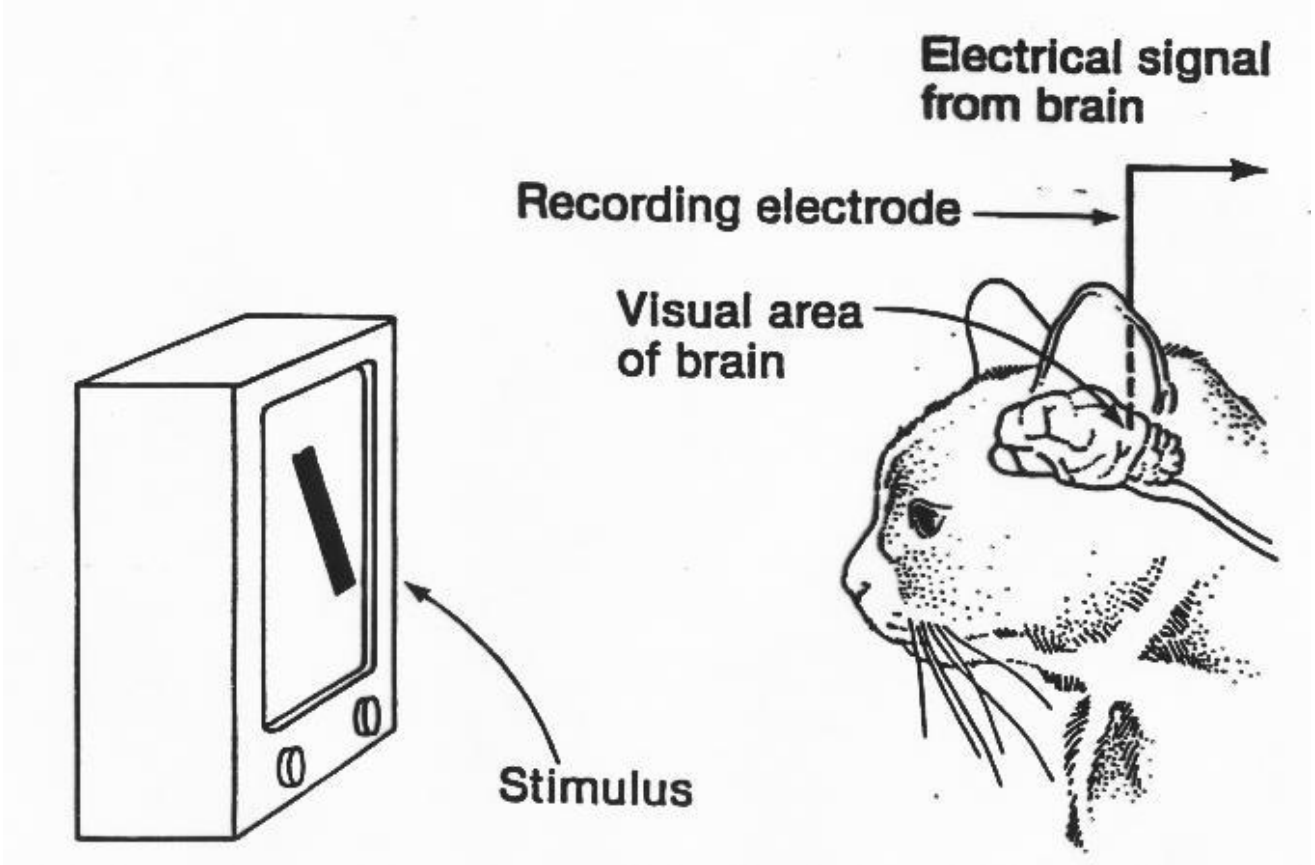


Image Credit: goodpsychology.wordpress.com

…and concluded that the cat's primary visual cortex neurons were only stimulated by certain angles of orientation

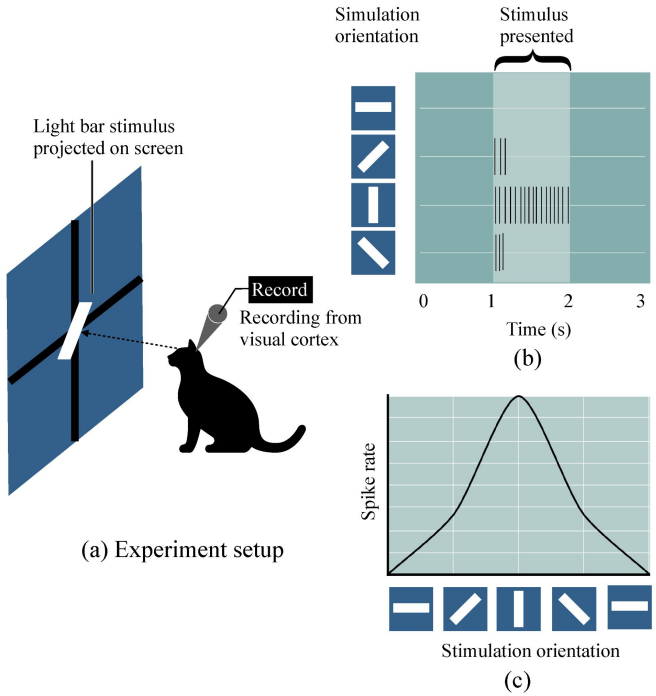
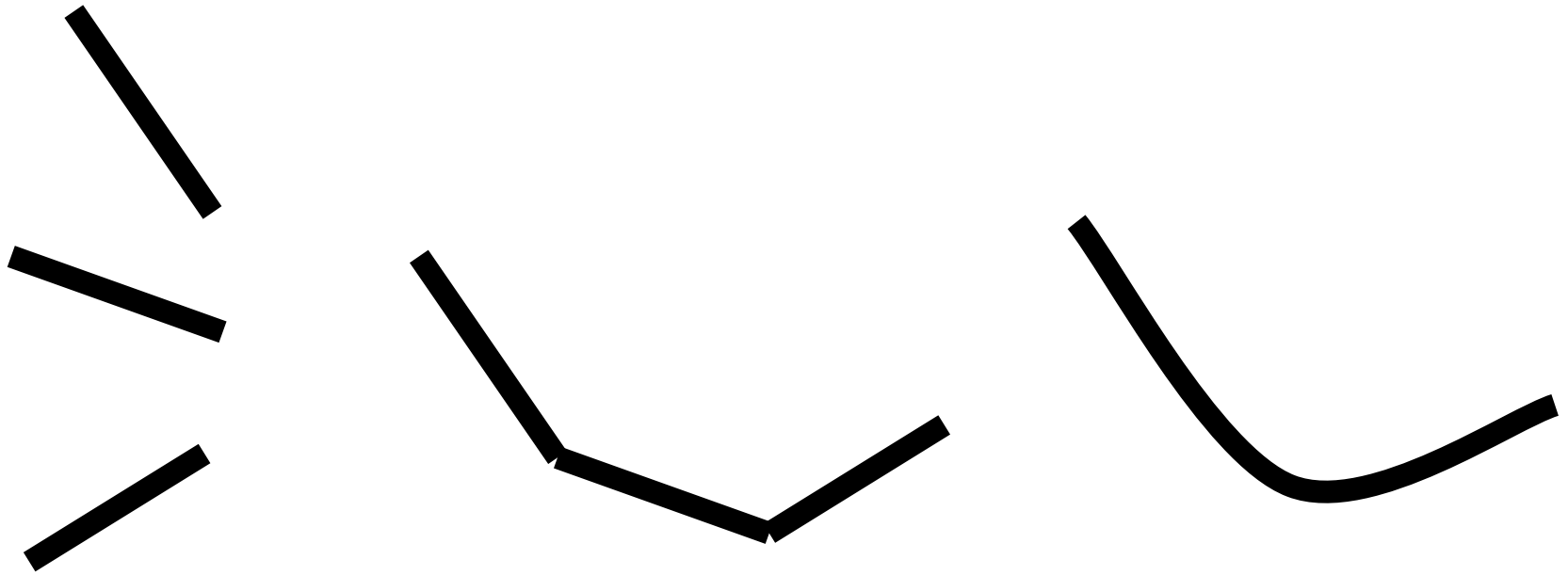


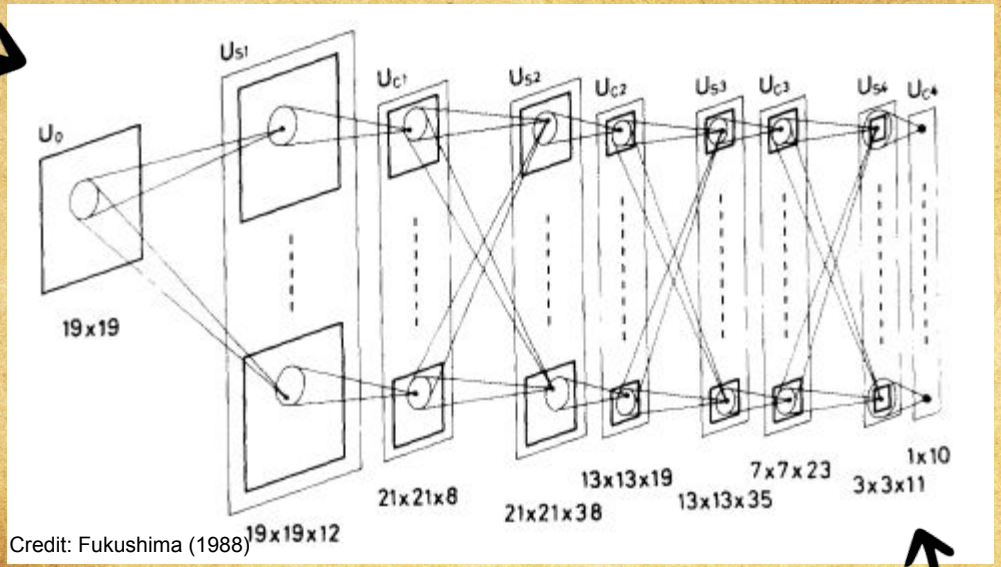
Figure 1. A neuron in the primary visual cortex responds selectively to line segments. Credit: Bin Li et al. (2022)



Simple neurons

Complex neurons

This is **Neocognition**, is the first convolutional neural network architecture.

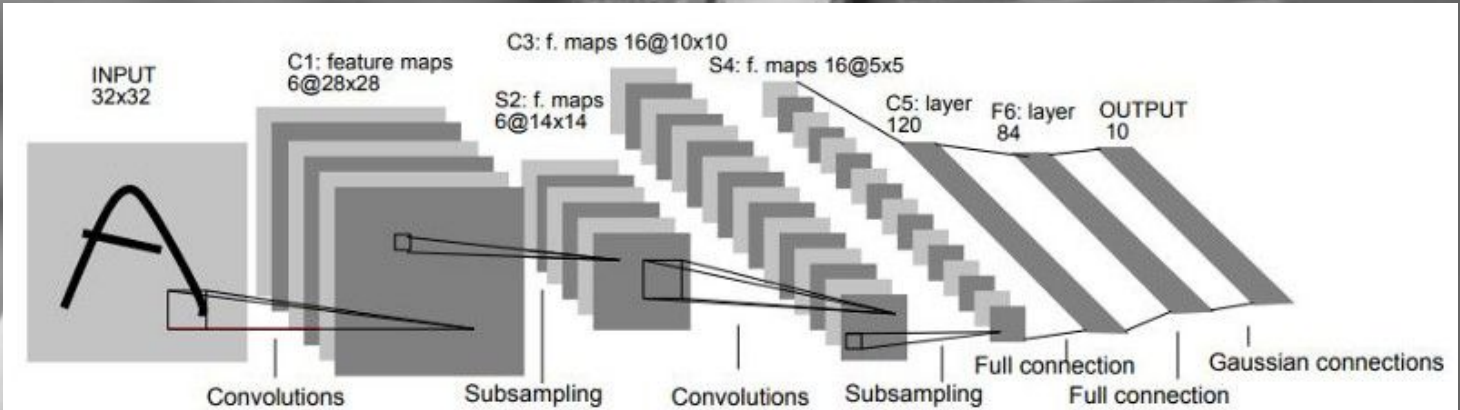


Credit: Fukushima (1988)

fi.edu/en/awards/laureates/kunihiko-fukushima

This is **Neocognition** was able to categorize handwritten digits.

Example: LeNet - 5

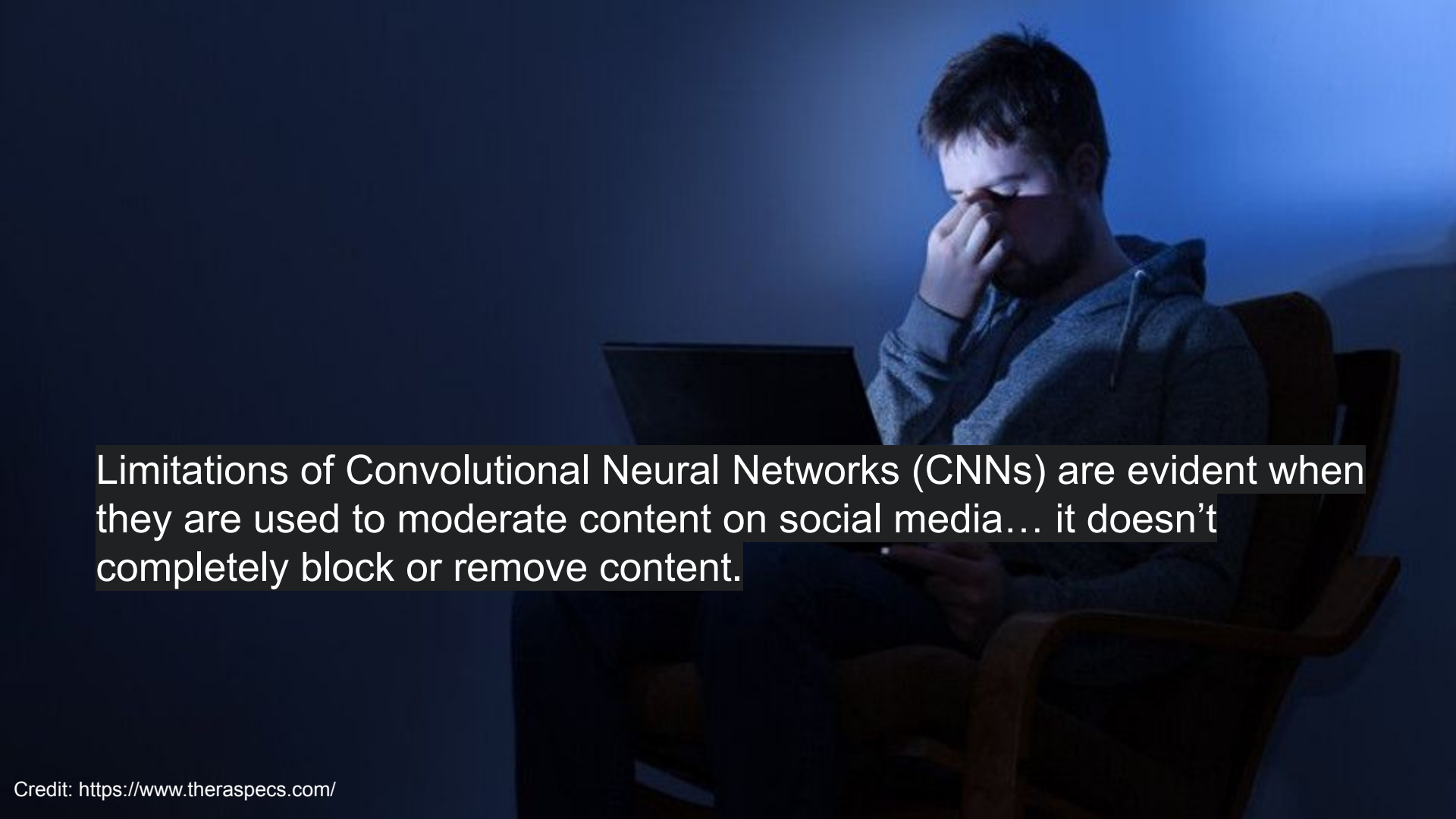


Credit: LeCun et al. (1998)

The neural network architecture shown above is called LeNet 5 and is used in the postal service.

Image Credit: Royal Mail

Convolutional neural networks are not **perfect**.



Limitations of Convolutional Neural Networks (CNNs) are evident when they are used to moderate content on social media… it doesn’t completely block or remove content.

Credit: https://www.theraspecs.com/

ImageNet

ImageNet is publicly released dataset containing 14 million labelled images and is used in classification and object detection tasks.

ImageNet

CNN's struggle with different lighting, extreme angles and parts of the object.

Machine learning is not about ‘thinking like a human’

Machine learning by default does not mimic human thinking…

Image by Freepik

Image by Freepik

World

Insight - Amazon scraps secret AI recruiting tool that showed bias against women

By **Jeffrey Dastin**

October 11, 2018 1:50 AM GMT+

Apple Card Investigated After Gender Discrimination Complaints

A prominent software developer said on Twitter that the credit card was "sexist" against women applying for credit.

INTERNET CULTURE

Google's algorithm shows prestigious job ads to men, but not to women. Here's why that should worry you.

By Julia Carpenter

July 6, 2015 at 4:43 p.m. EDT

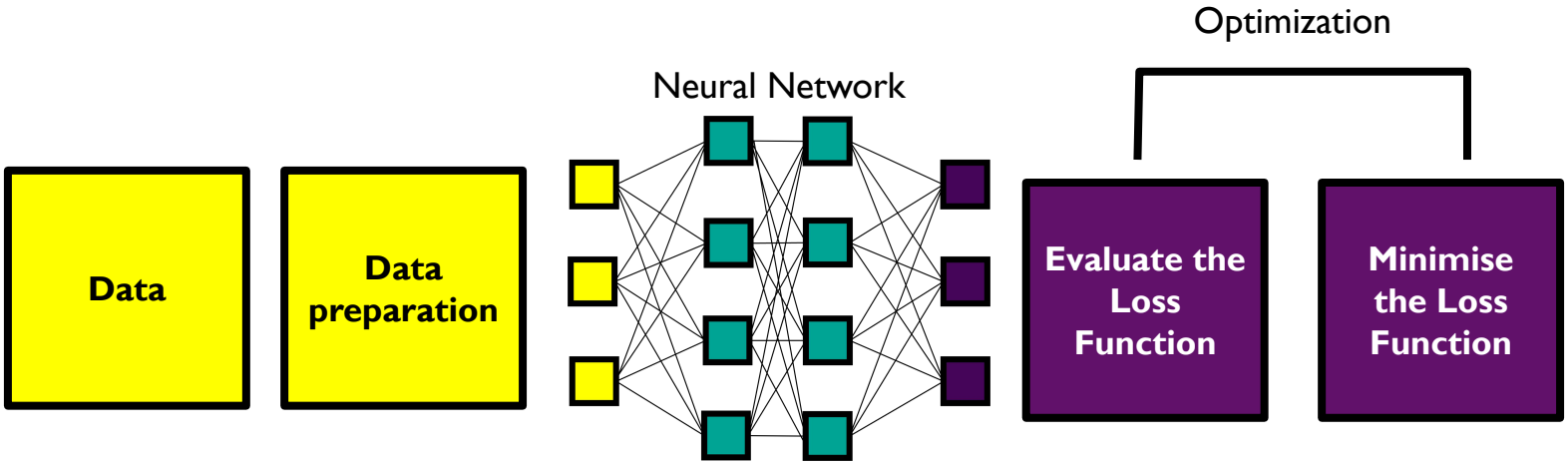
POLICY

Predictive policing is still racist—whatever data it uses

Training algorithms on crime reports from victims rather than arrest data is said to make predictive tools less biased. It doesn't look like it does.

By Will Douglas Heaven February 5, 2021

Bias can be injected into a machine learning pipeline at various stages…



…including how the problem is framed.

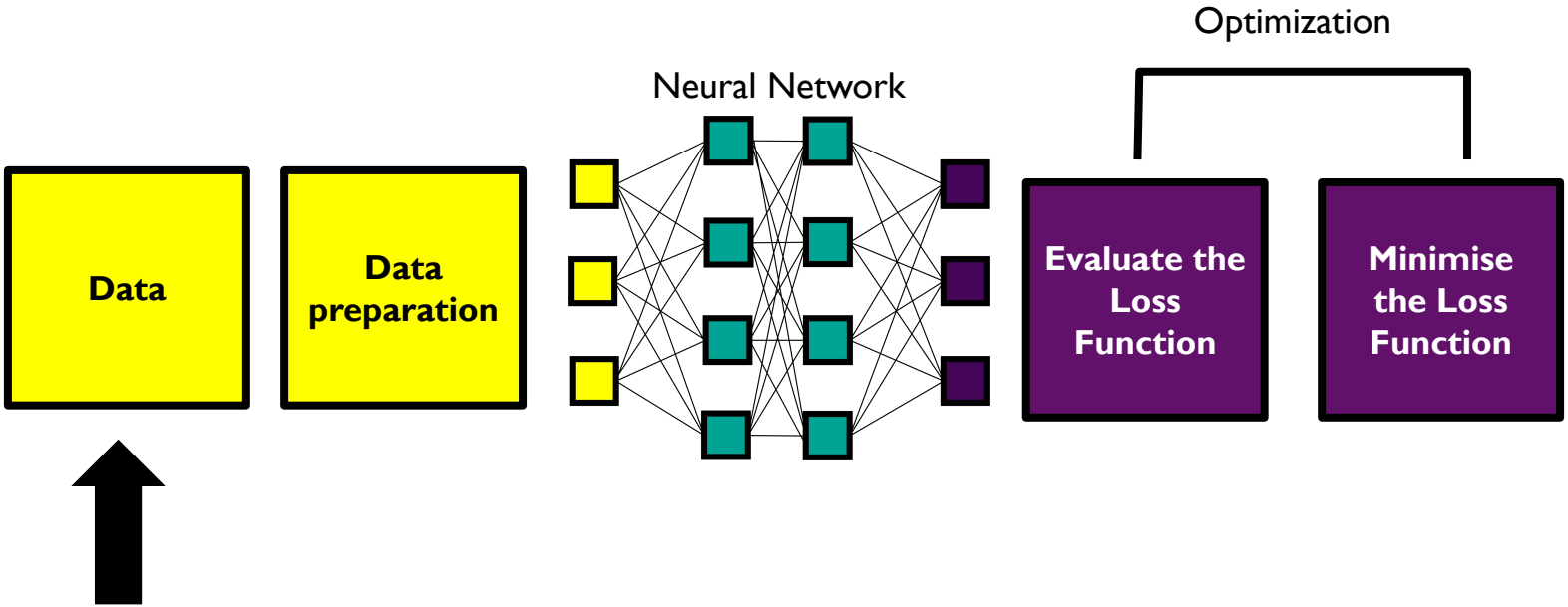
You’re machine learning engineers, let’s predict whether England will win the Euros 2024.

Credit: sky

Credit: sky

Credit: Sky

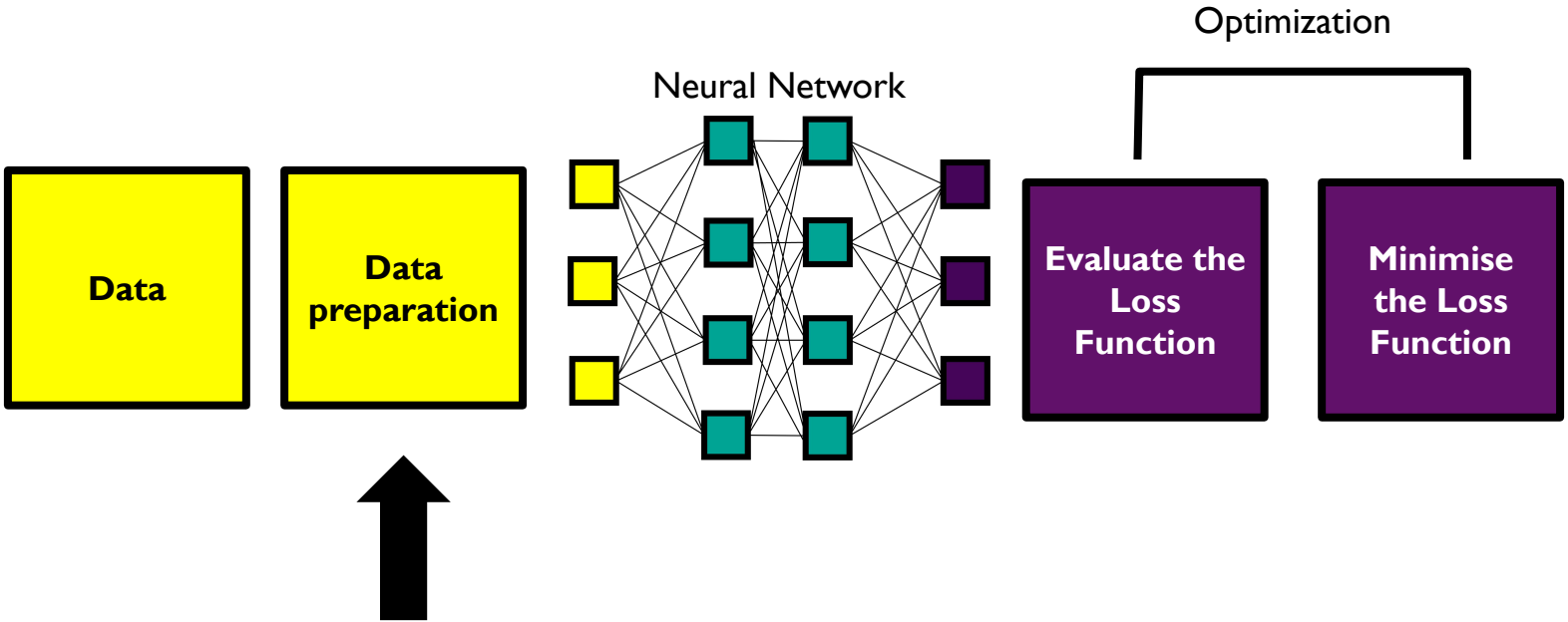
Bias can be injected into a machine learning pipeline at various stages…



…including how the problem is framed.

Nom. goals scored
Hobbies
Height
Nom. red cards
Hair Colour
Goal attempts
UEFA EURO 2020
Credit: Sky

Bias can be injected into a machine learning pipeline at various stages…



…including how the problem is framed.

Nom. goals scored

Height

Nom. red cards

Goal attempts

Credit: Sky

Junk in = Junk out

Why is machine learning bias hard to fix?

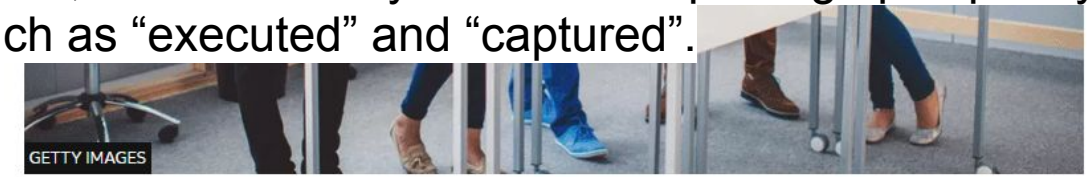
1) Not obvious

Credit: technologyreview.com

Amazon scrapped 'sexist AI' tool

10 October 2018

The neural network was reprogrammed to ignore explicitly gendered words, like “woman”, but then the system started picking up implicitly gendered words, such as “executed” and “captured”.



The algorithm repeated bias towards men, reflected in the technology industry

An algorithm that was being tested as a recruitment tool by online giant Amazon was sexist and had to be scrapped, according to a Reuters report.

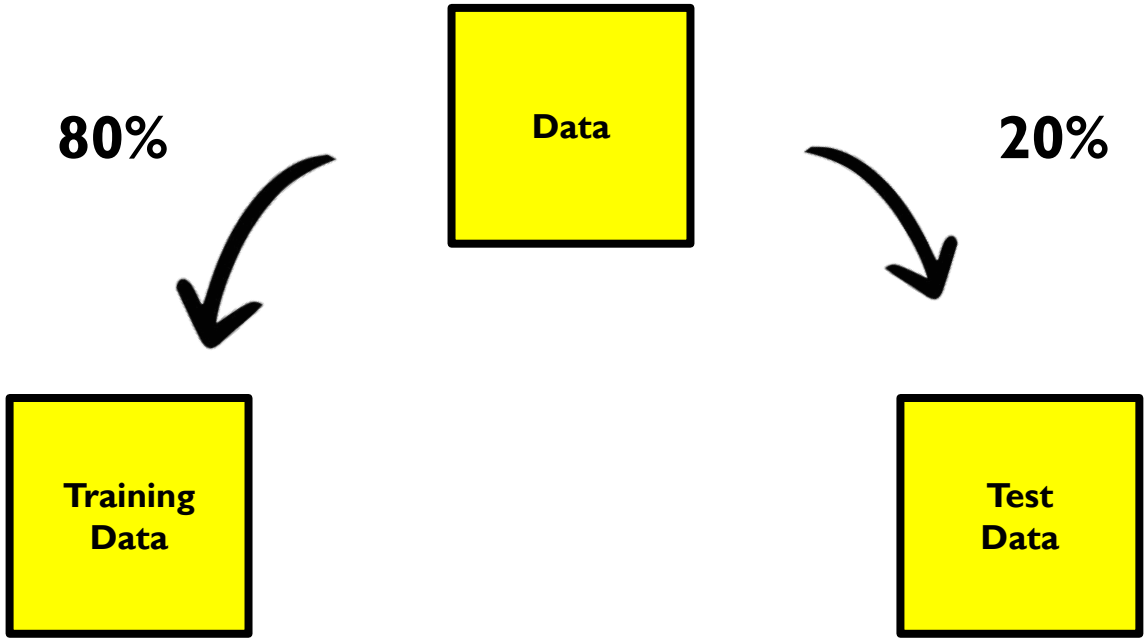
The artificial intelligence system was trained on data submitted by applicants over a 10-year period, much of which came from men, it claimed.

Credit: BBC

Why is it hard to fix?

1) Not obvious
2) Imperfect process

Credit: technologyreview.com


80%
Data
20%
Training Data
Test Data

Why is it hard to fix?

1) Not obvious
2) Imperfect process
3) Lack of social context

Credit: technologyreview.com

United Kingdom

Image Credit: gpointstudio on Freepik

India

Image Credit: rawpixel.com on Freepik

Why is it hard to fix?

1) Not obvious
2) Imperfect process
3) Lack of social context
4) The definitions of fairness

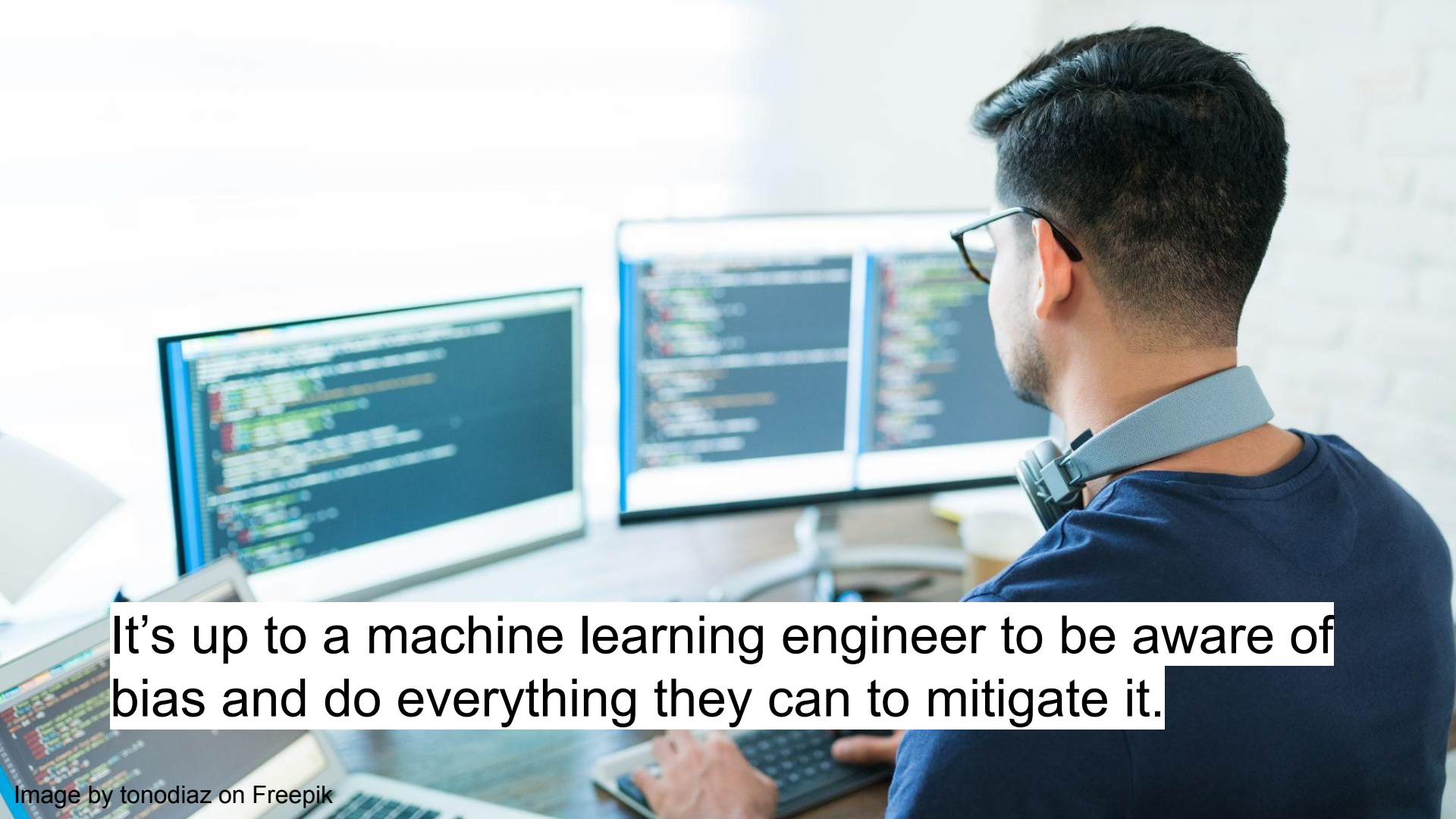
Credit: technologyreview.com

What is ‘fairness’?

50% of men and 50% of women are considered high risk?

Everyone considered high risk?

Image Credit: Freepik



It’s up to a machine learning engineer to be aware of bias and do everything they can to mitigate it.

Image by tonodiaz on Freepik

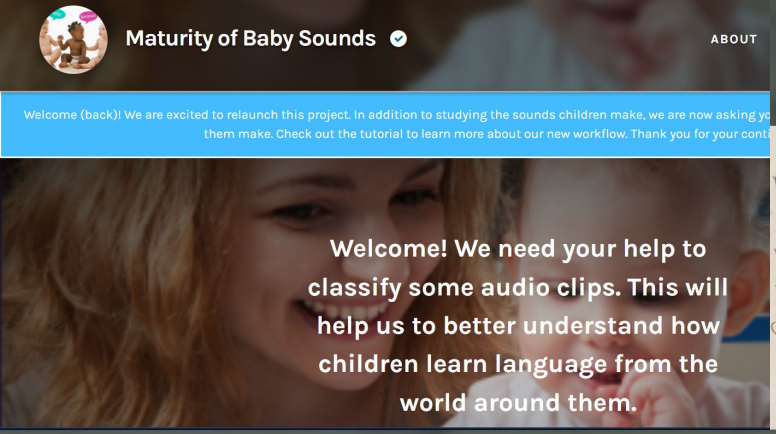
Image Credit: krakenimages.com on Freepik

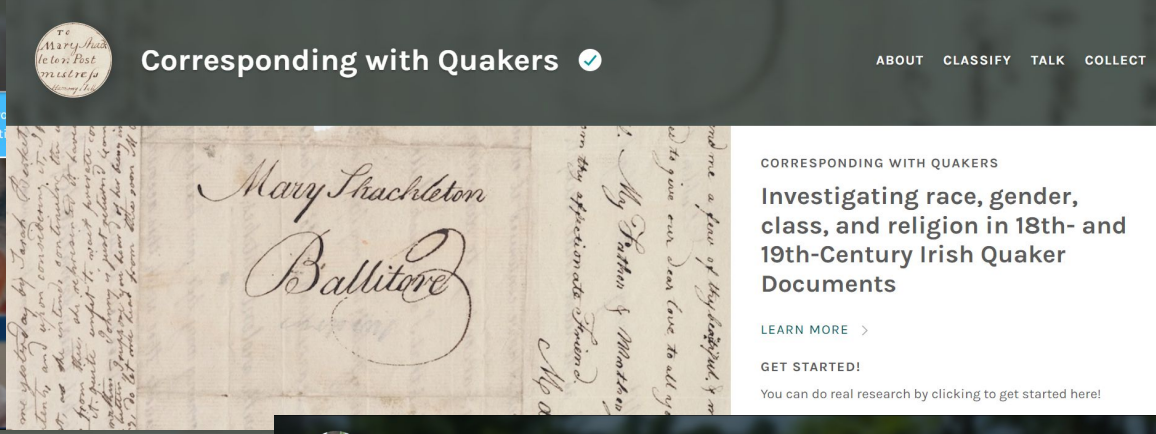
Maybe **you** could be the solution?

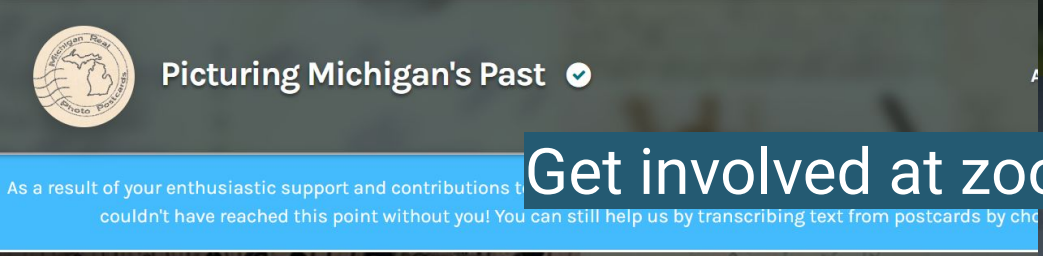
This is how you can

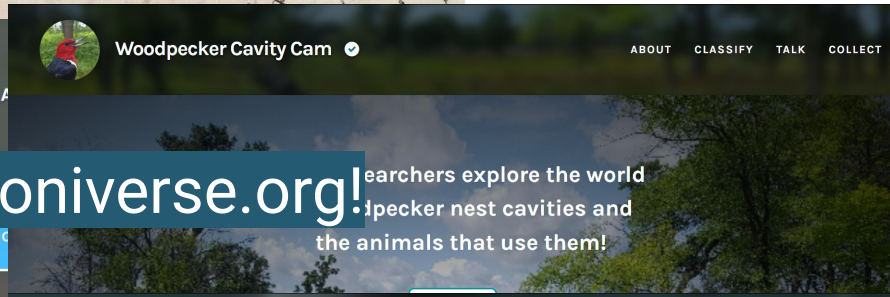
help...

Image Credit: benzoix on Freepik

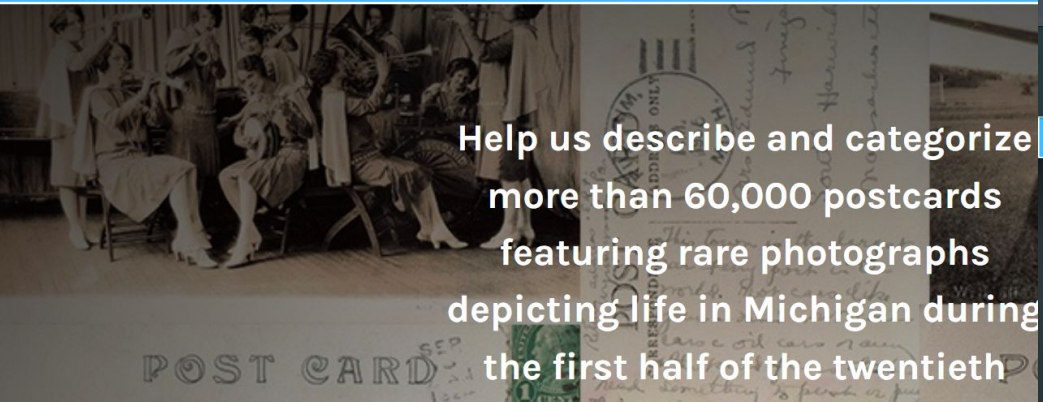


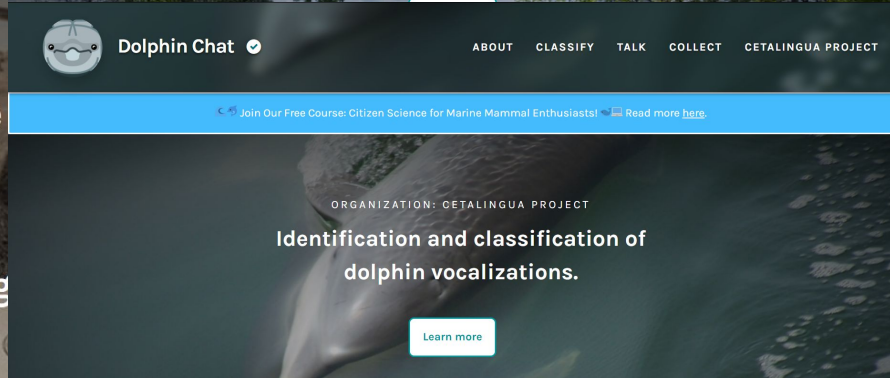






Get involved at zooniverse.org!





Black Hole Hunters

Galaxy Zoo

Language English

ABOUT CLASSIFY TALK COLLECT

Few have witnessed what you're about to see

Learn more Get started

Planet Hunters NGTS

ABOUT

Get involved at zooniverse.org!

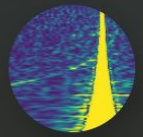
Dark Energy Explorers

Identify distant galaxies to help measure dark energy when the universe was just ~2-3 billion years old

Learn more

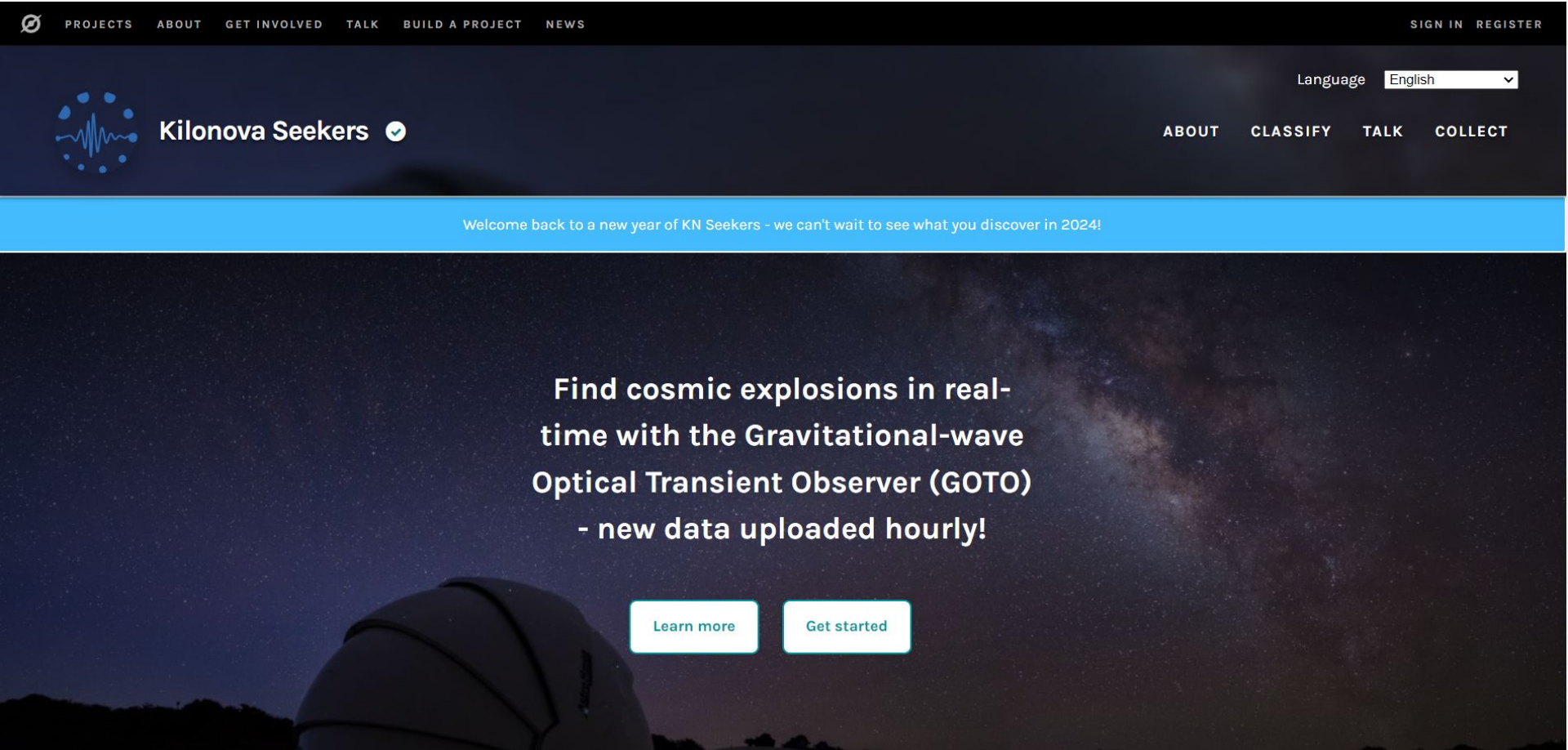
Discover hidden worlds with the Next-Generation Transit Survey

Learn more

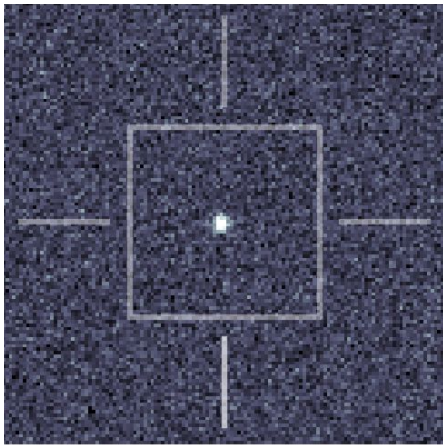


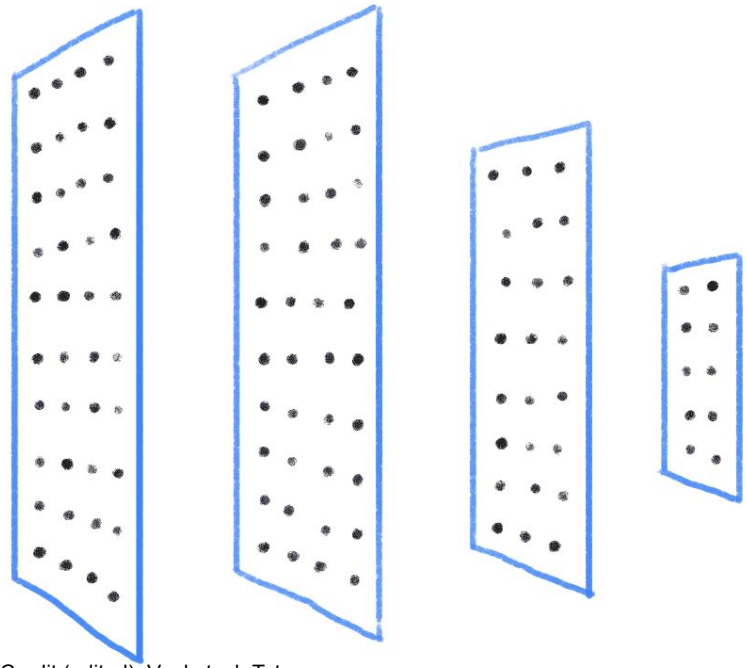
Gravity Spy

We need you to help us identify the physics…



…in this research a neural network is uncertain about whether it has observed an explosion and we need you to clarify!





Credit (edited): Venkatesh Tata

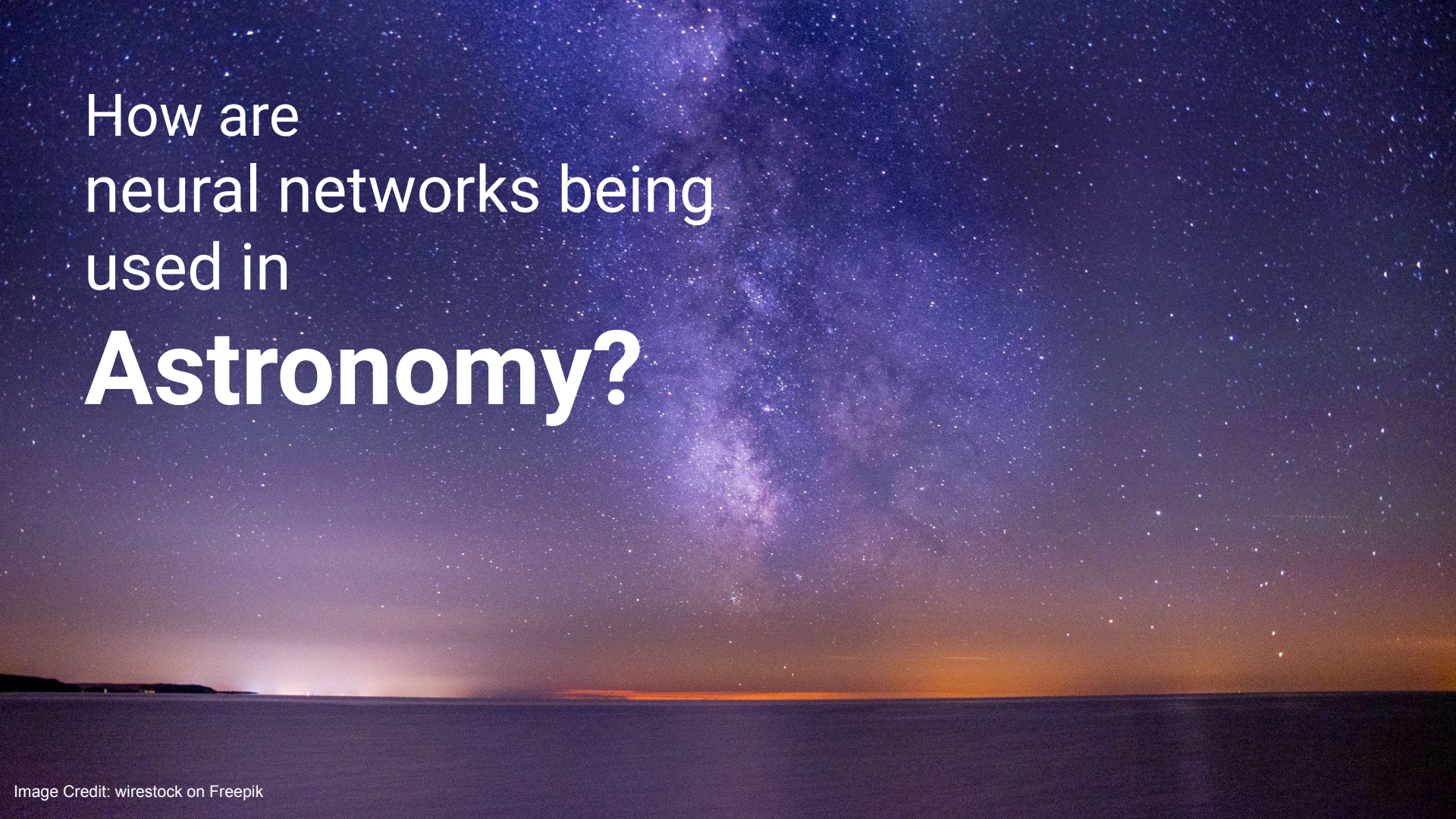
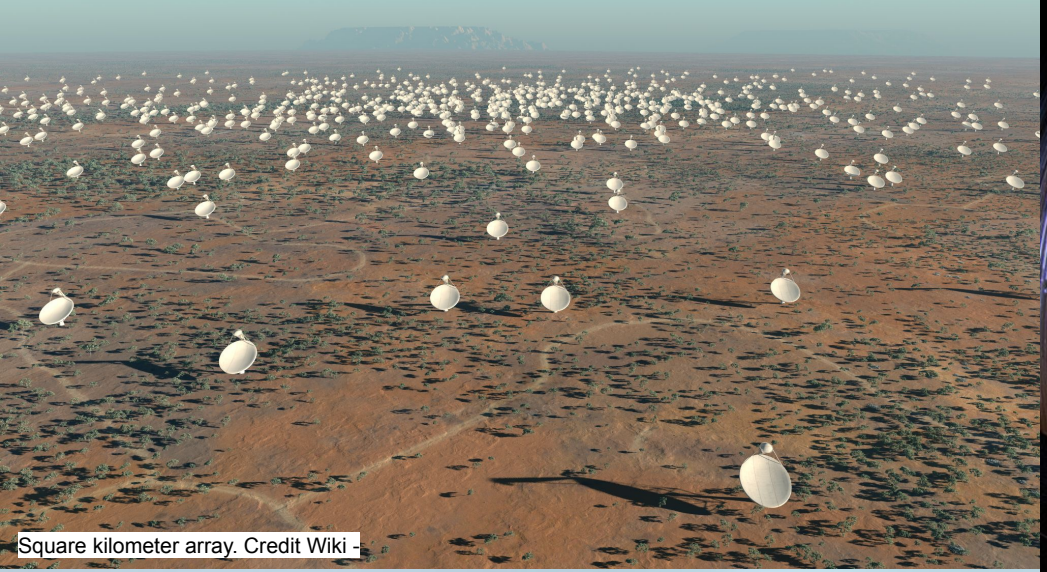
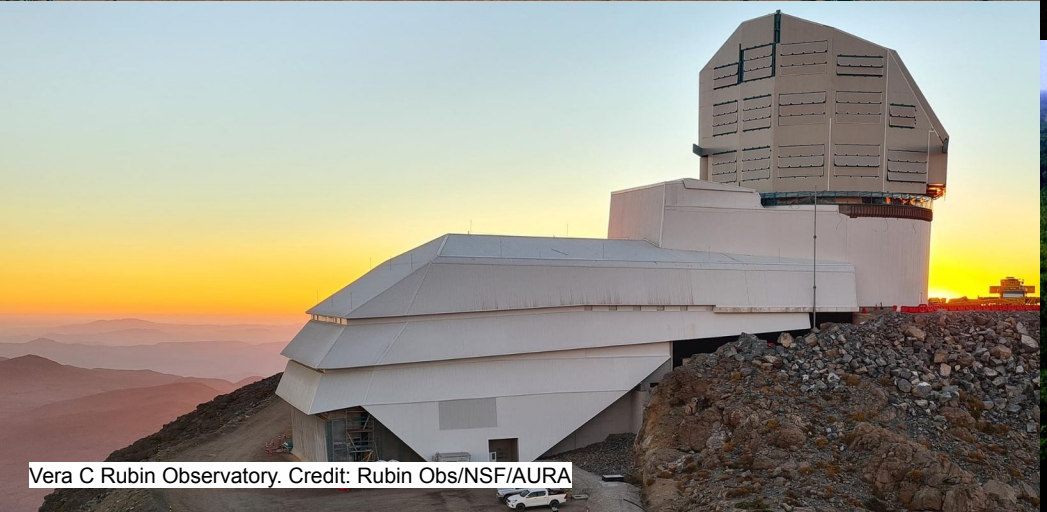


Image Credit: wirestock on Freepik



Square kilometer array. Credit Wiki -

The Victor M. Blanco 4-meter telescope building Credit DES



Vera C Rubin Observatory. Credit: Rubin Obs/NSF/AURA

Gravitational wave detector. Credit: Ligo

Image by cookie_studio on Freepik

In 2023, a neural network (with human supervision) identified 527 new strong lensing candidates, a rare event where light bends around heavy objects like galaxies.

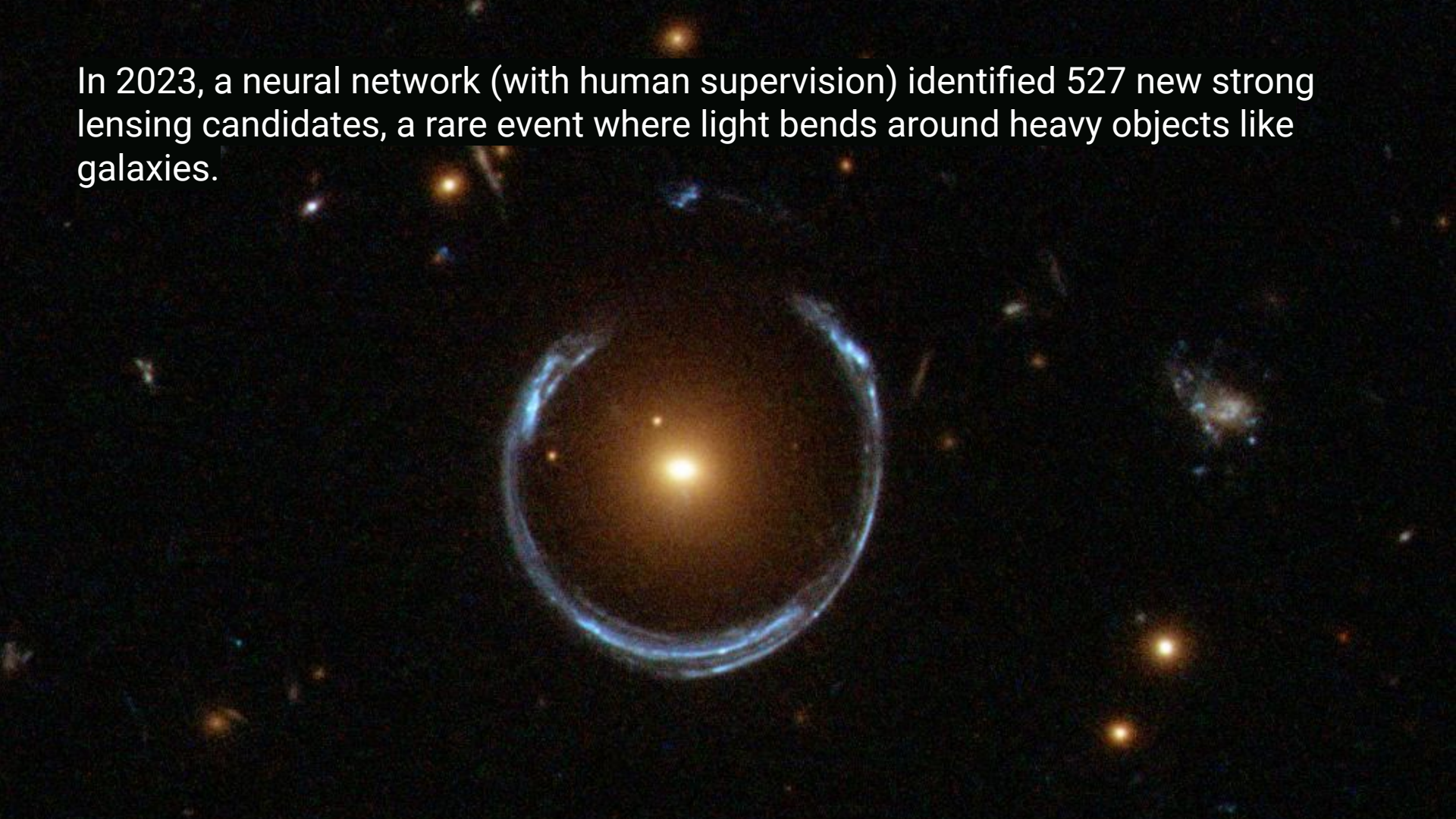
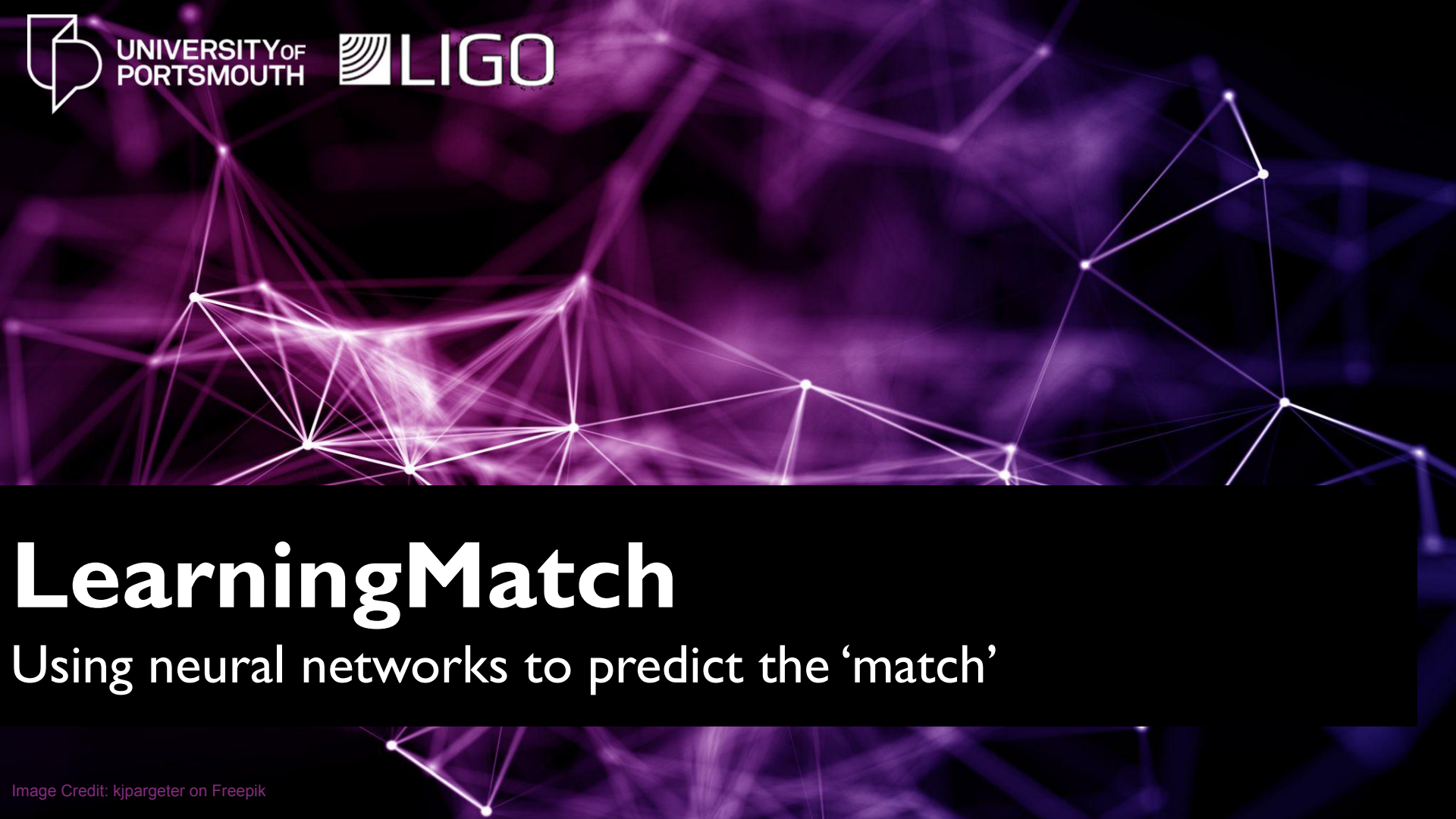


Image Credit: vector_corp

Neural networks are challenging some of our theories of galaxy evolution by classifying the galaxies differently… new physics?

Image Credit: NASA, ESA, ADAM G. RIESS (STSCI, JHU) - https://scitechdaily.com/images/Hubble-Space-Telescope-Galaxy-Collection.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=118249156



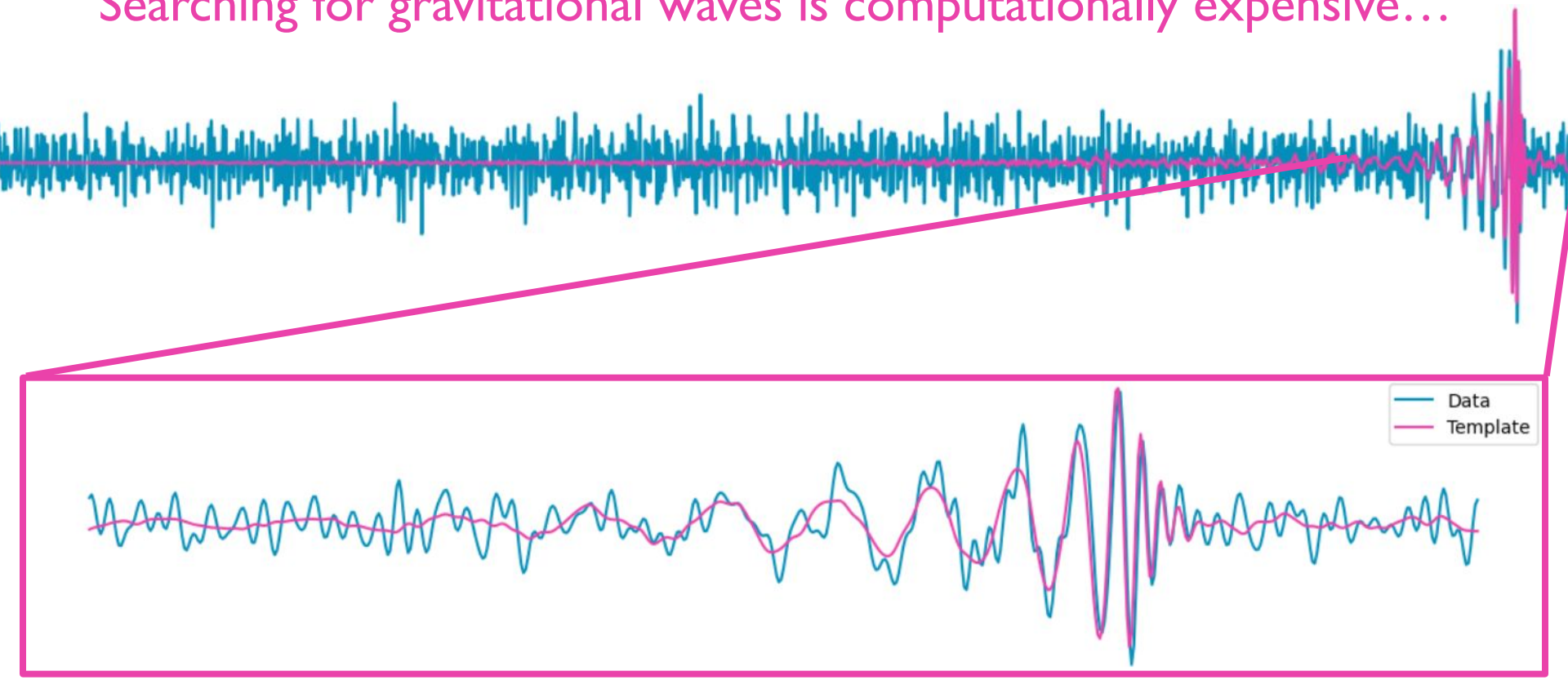
LearningMatch

Using neural networks to predict the ‘match’

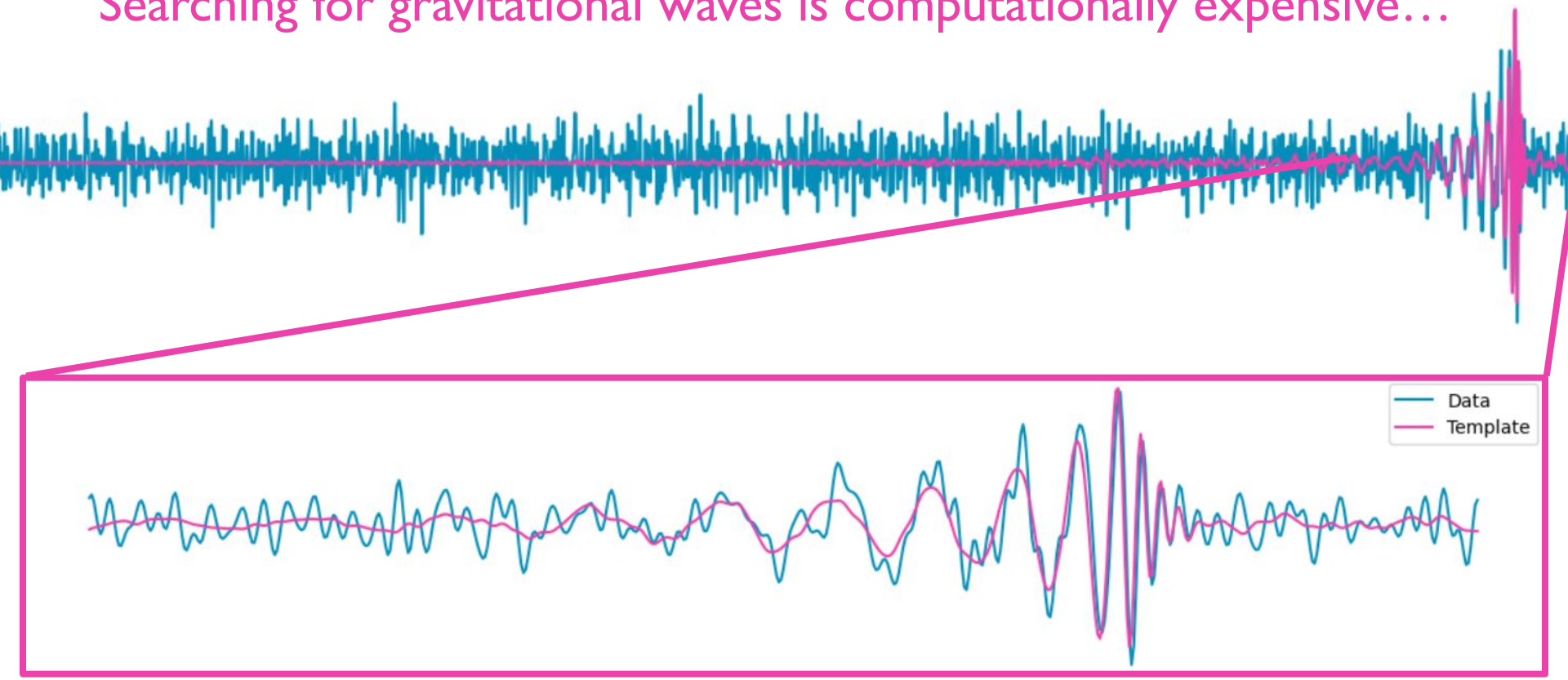
Image Credit: kjpargeter on Freepik

Gravitational Waves are ripples in the curvature of spacetime produced by **accelerating masses**… such as two **black holes** or two **neutron stars** colliding.

Searching for gravitational waves is computationally expensive…



Searching for gravitational waves is computationally expensive…



…so we want to use neural networks to speed up the process.

What is the ‘**match**’?

What is the '**match**'?

* is the Complex conjugate of a function
~ is the Fourier Transform

Templates - which are a function of mass, spin and other parameters

$$\mathcal{M}(h_1, h_2) = \max_{\phi_c, t_c} \langle h_1 | h_2(\phi_c, t_c) \rangle$$

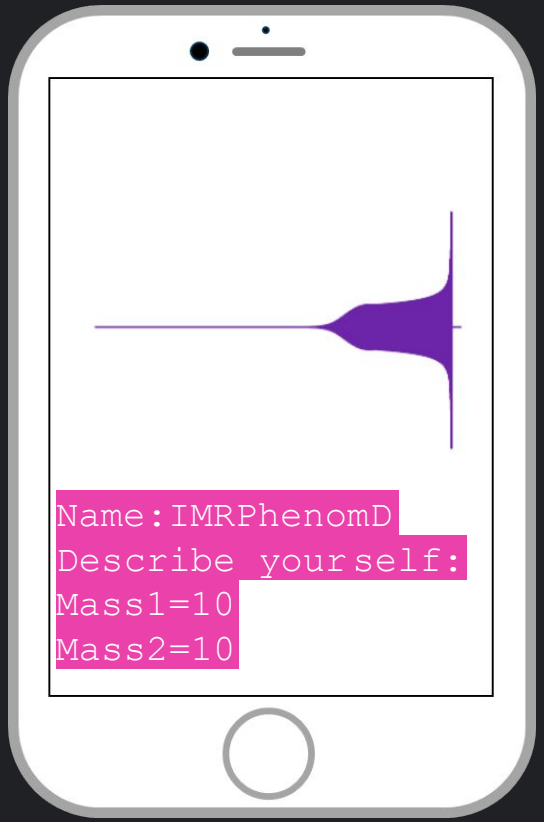
$$= \max_{\phi_c, t_c} \left[4\Re \int_0^\infty \frac{\tilde{h}_1^*(f)\tilde{h}_2(f)}{S_h(f)} \right]$$

One-sided Power Spectral Density (PSD) - average noise in our detectors

\\ The match is the weighted inner product maximized over the phase and the time of coalescence.

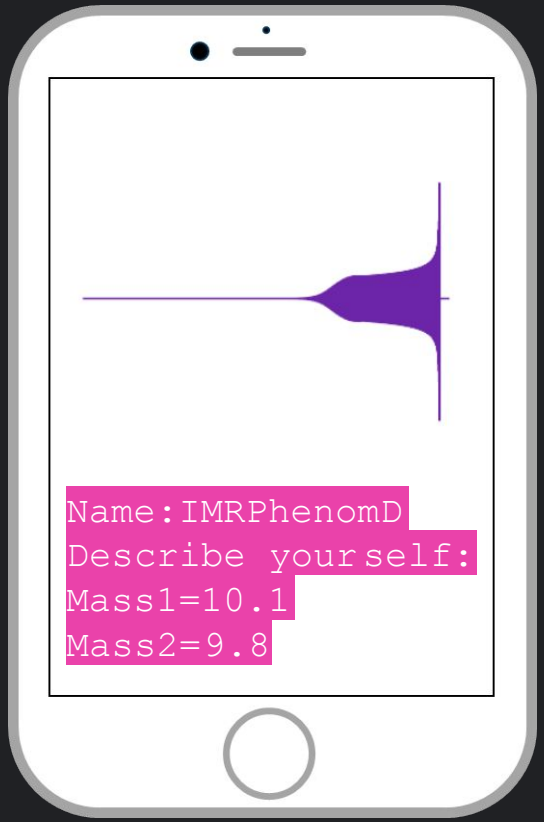
What is a good ‘**match**’?

// It’s like gravitational wave online dating!



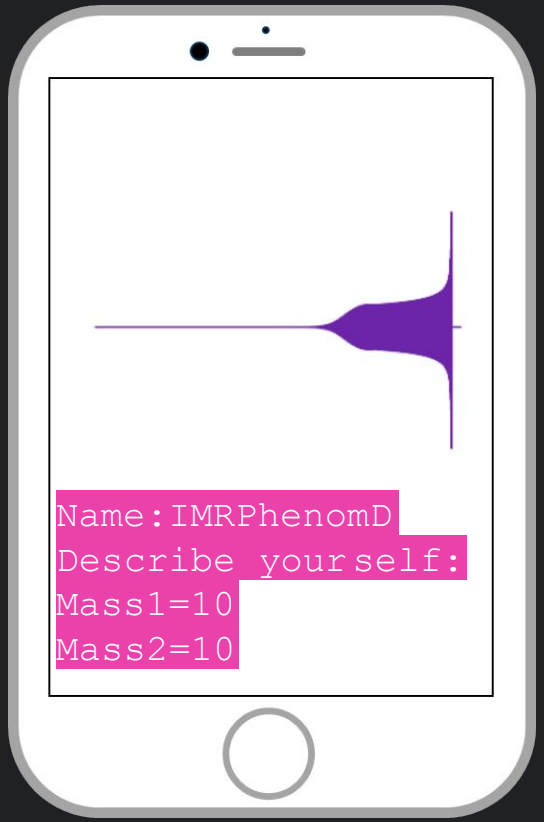
STRONG MATCH

= 0.99 (or～1)



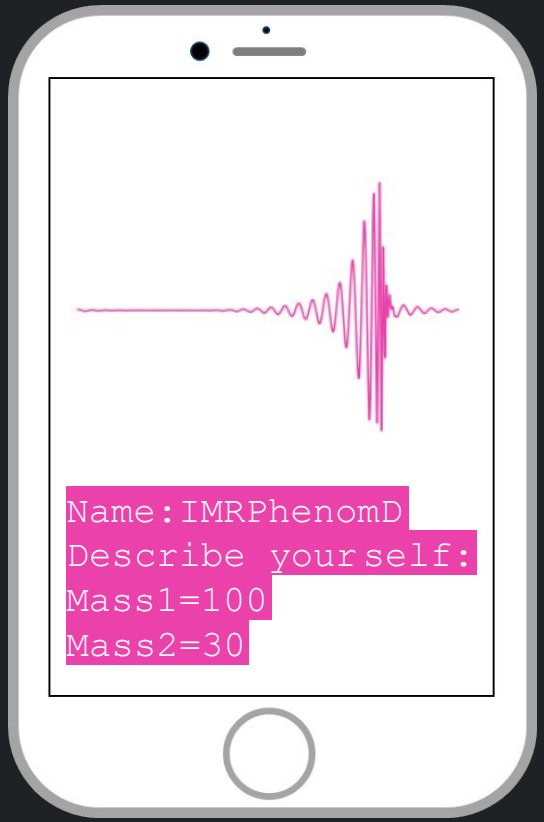
What is a good **‘match’**?

// It’s like gravitational wave online dating!

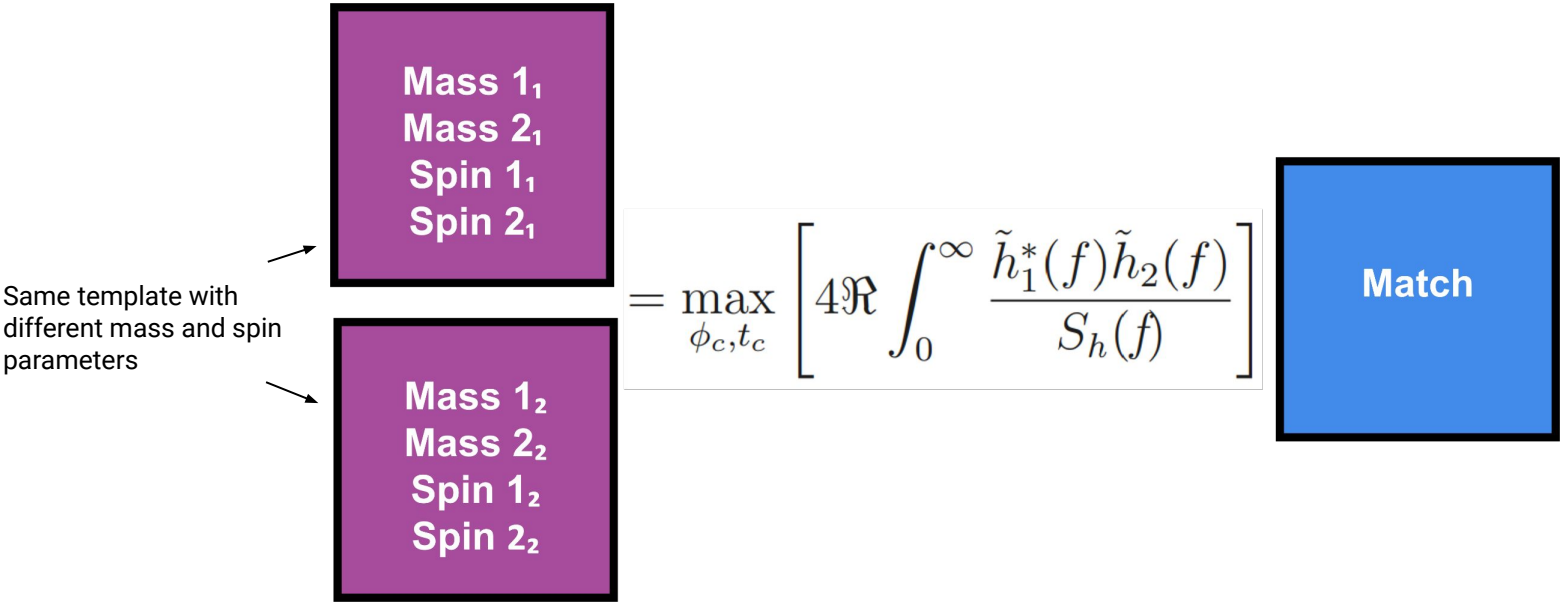


WEAK MATCH

= 0.01

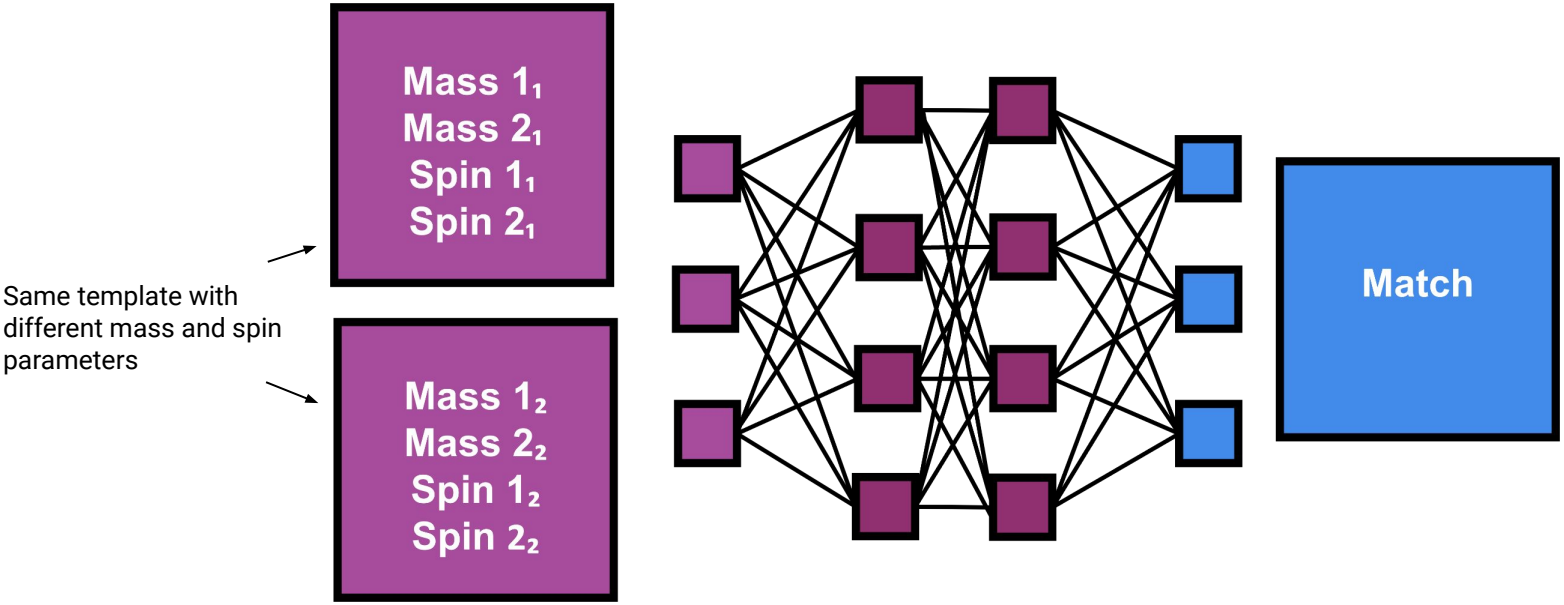


The Aim:



The aim of the neural network is to learn the relationship between the parameters and the match.

The Aim:



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…this is why machine learning engineers are paid nice salaries!

Using neural networks in astronomy is still current research…

AI generated image. Credit: freepik

Using neural networks in astronomy is still current research…

…so who knows what the **future** looks like!

AI generated image. Credit: freepik

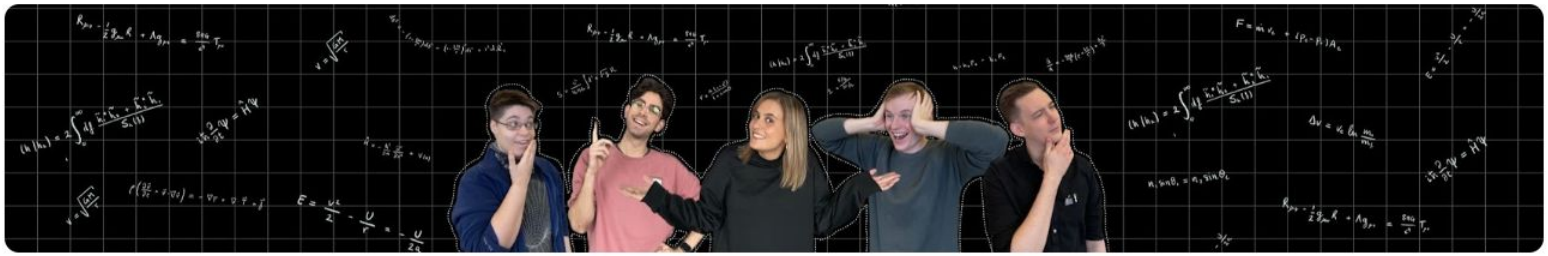
Are machines the next Einstein?

Thank you for listening and are there any questions?

Scan here to get involved with an astronomy project from your phone... we need you!

Get involved at zooniverse.org!

physics chat field of view



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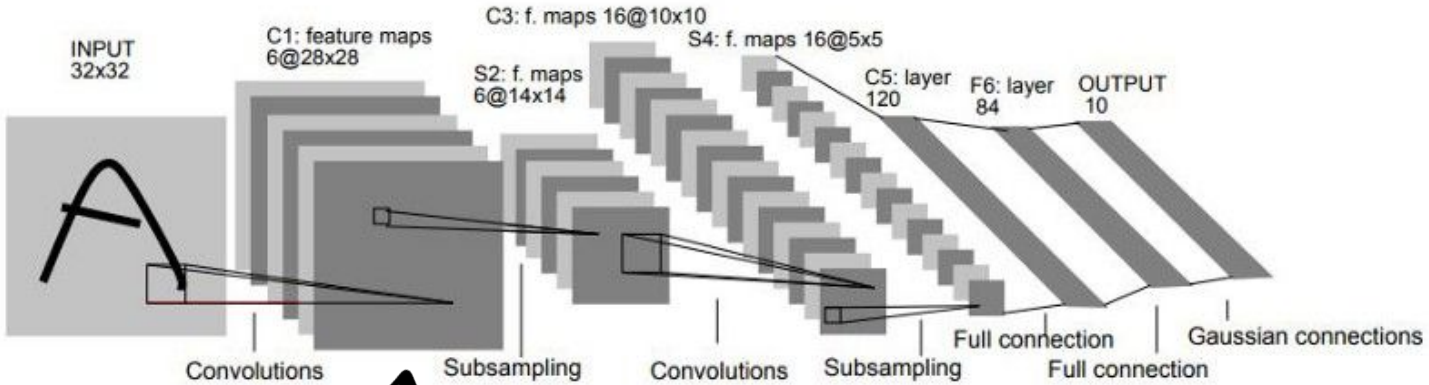
Additional Slides



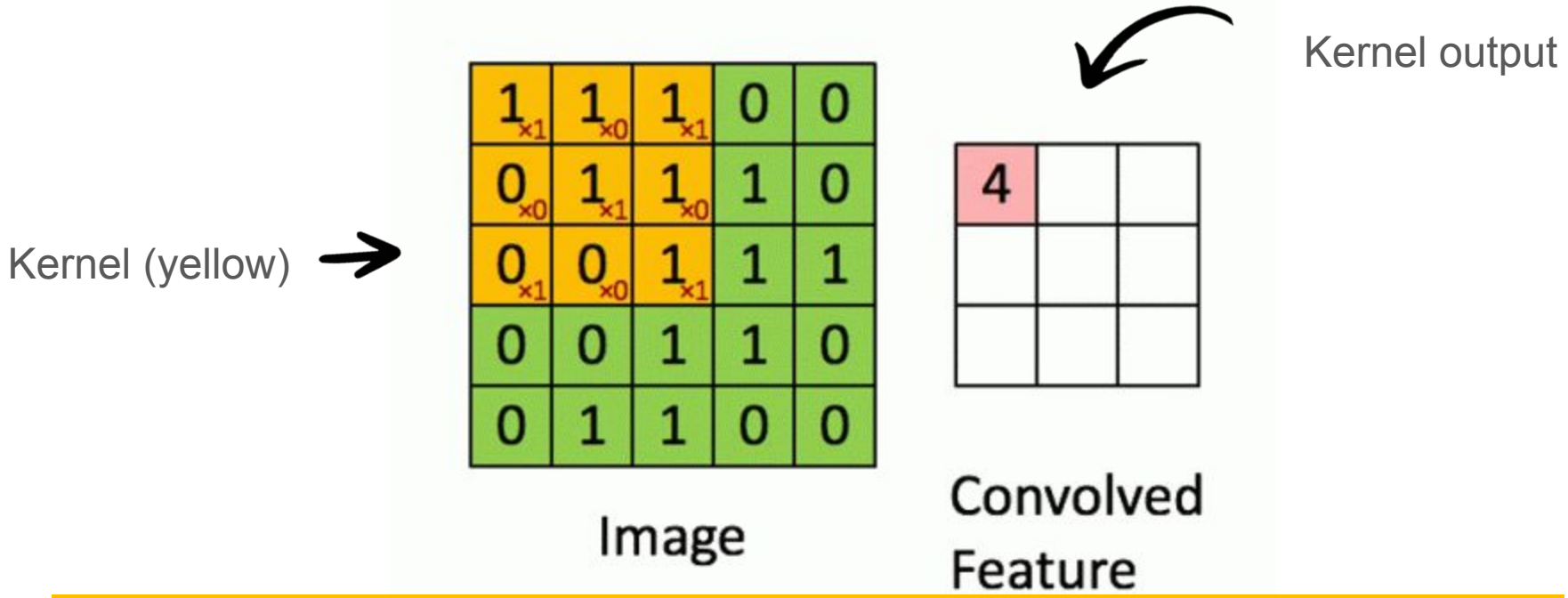
Credit: LeCun et al. (1998)

Convolutional layer

Neural Network

Image → Feature Extraction → Neural Network → Output

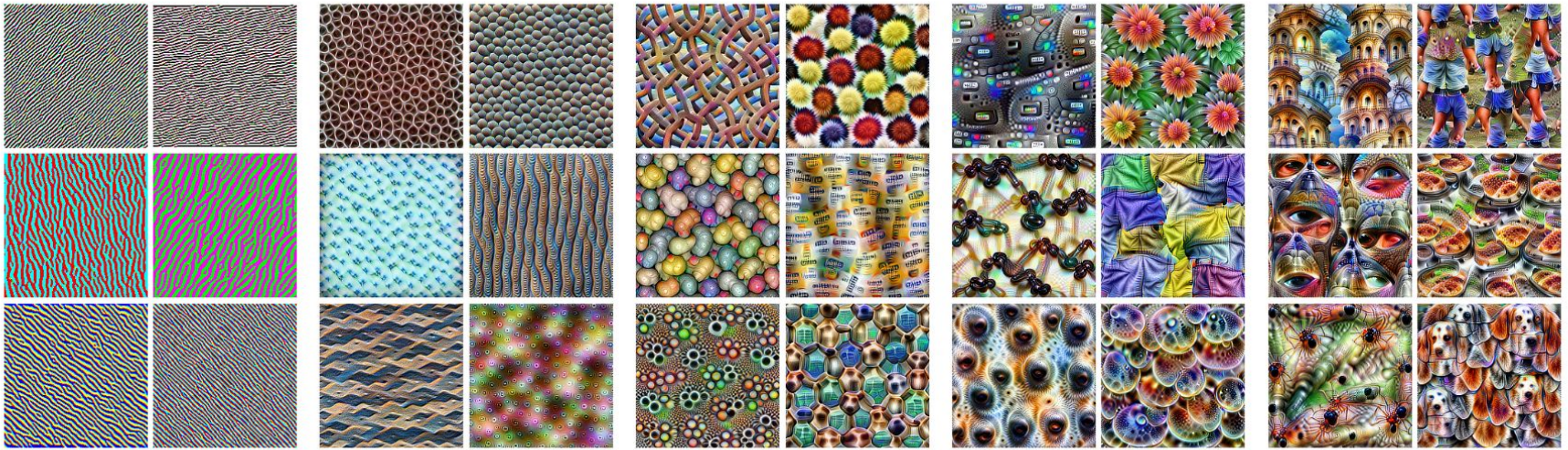
What is a convolutional layer?



A convolutional layer extracts certain information from the image (i.e. lines at a particular orientation). The output is what the NN sees.

Feature Visualization

How neural networks build up their understanding of images



Edges (layer conv2d0) **Textures** (layer mixed3a) **Patterns** (layer mixed4a) **Parts** (layers mixed4b & mixed4c) **Objects** (layers mixed4d & mixed4e)

Check out ‘Colah’s blog’ for more information on convolutional layers!