Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

00 - Introduction

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[4C16/5C16] Deep Learning and its Applications — 2022/2023

[4C16] Deep Learning and its Applications

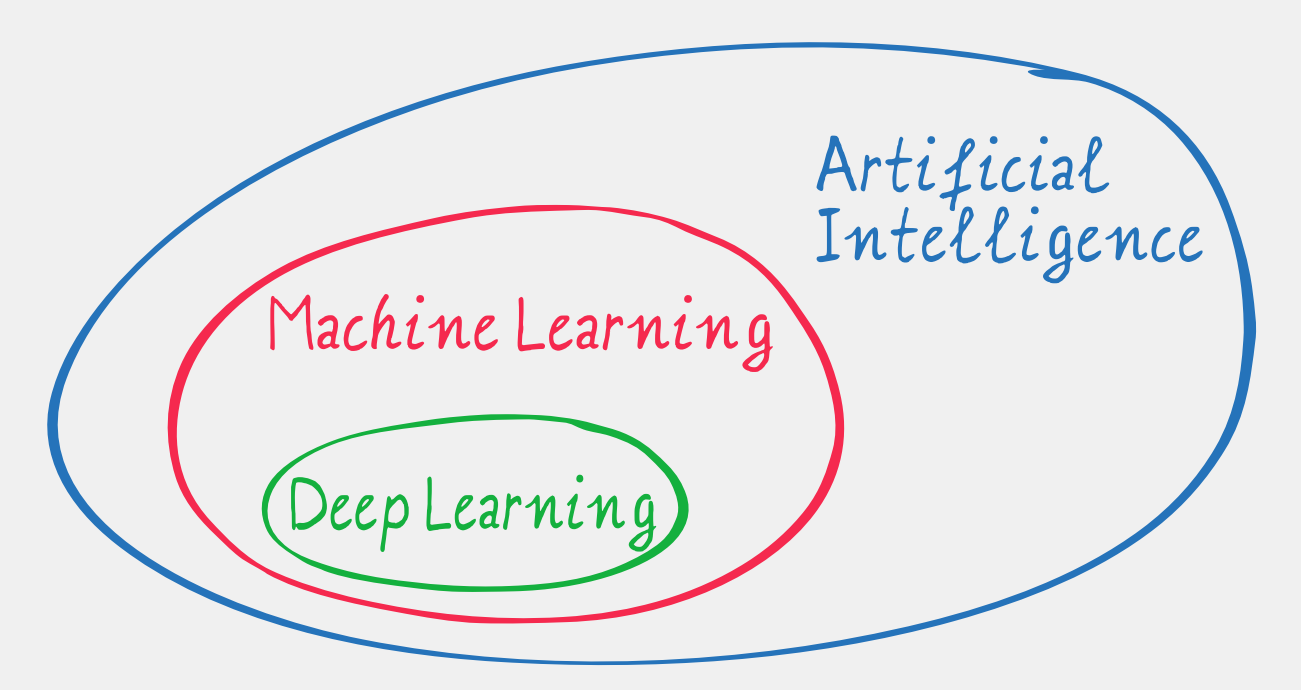
This module is an introduction to Machine Learning and especially Deep Neural Nets, which are disrupting all aspects of society today.

The material is constructed in collaboration with leading industrial practitioners including Google, YouTube and Movidius/Intel.

Hands on labs will give you experience with these applications.

Deep Learning is a particular type of **machine learning** method, and is thus part of the broader field of **artificial intelligence** (using computers to reason).

Deep learning is another name for **artificial neural networks**, which are inspired by the structure of the neurons in the cerebral cortex.



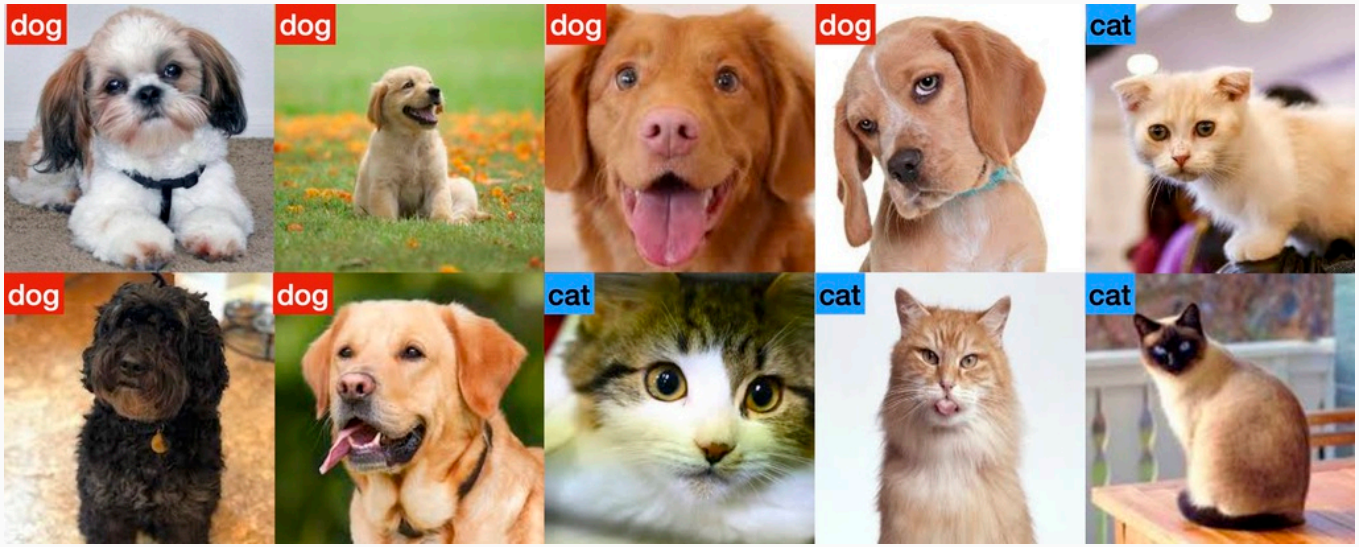
The recent quantum leap in machine learning has solely been driven by deep learning successes.

When you read or hear about AI or machine Learning successes in recent years, it really means Deep Learning successes.

Machine Learning can be split into 3 main fields:

1. Supervised Learning

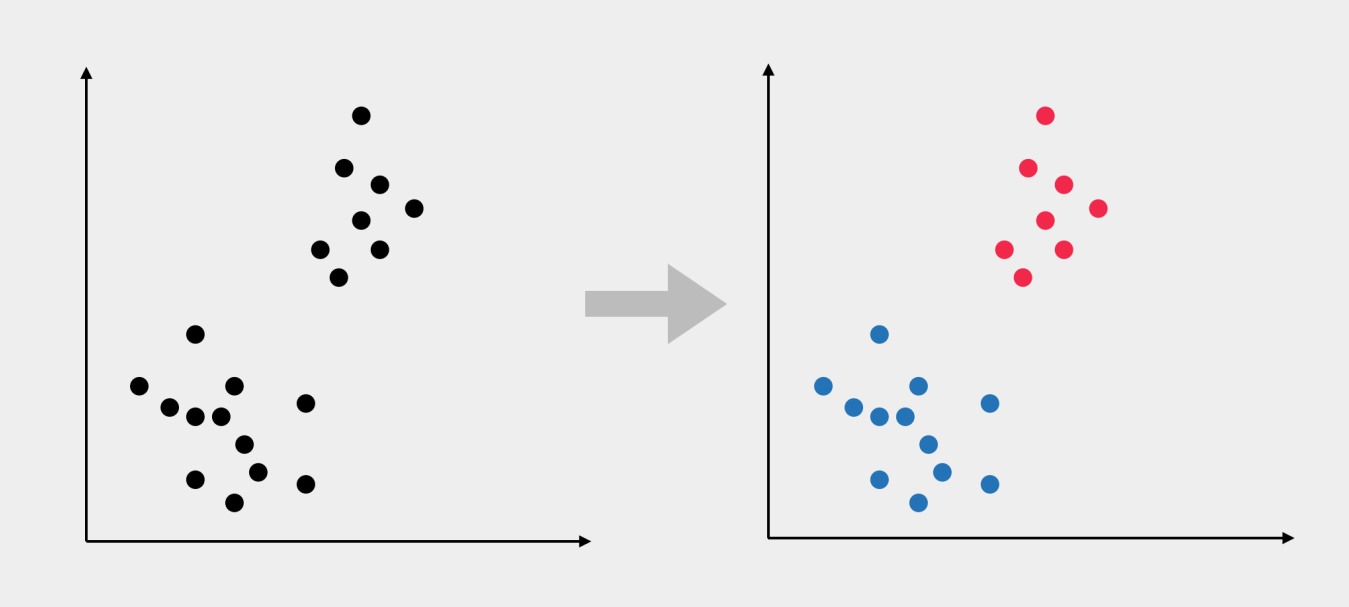
We have a labelled dataset $(\mathbf{x}_i, y_i)_{i \in \{1..n\}}$ containing features $\mathbf{x}_i$ (eg. the image pixels) and outcomes y_i (eg. cat=0/dog=1 label).



Can we find a model $f(\mathbf{x}_i) = y_i$ to predict the outcome from the input features?

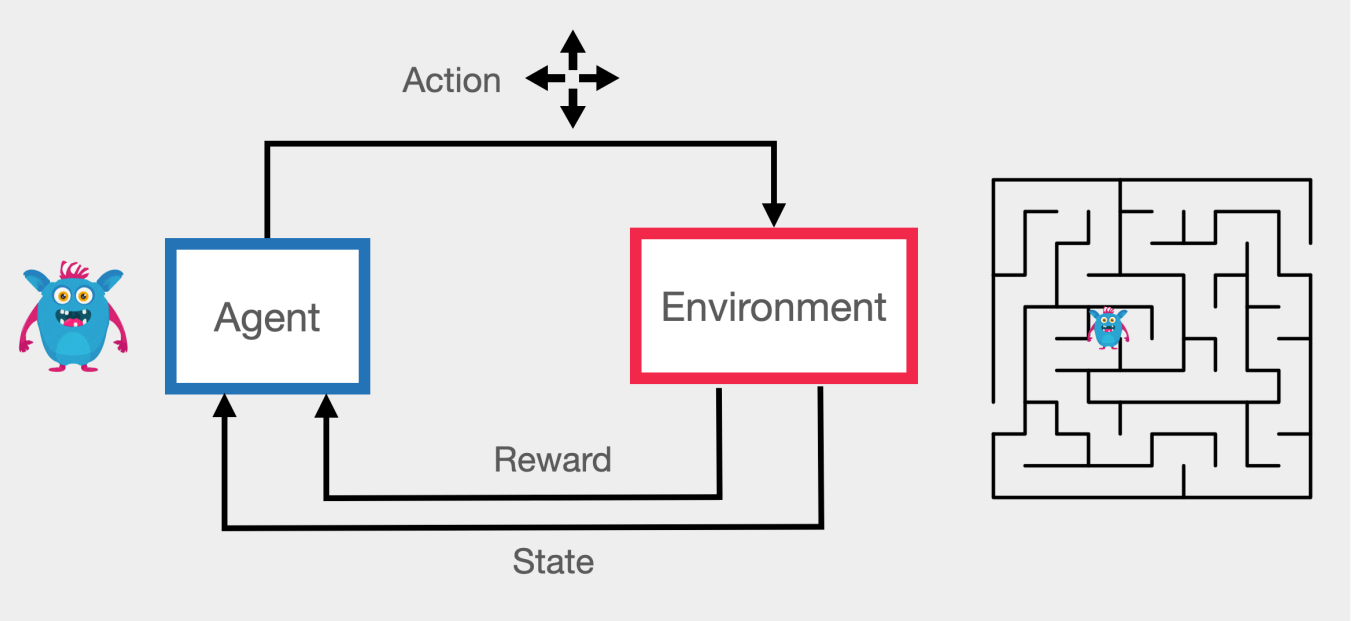
2. Unsupervised Learning

What can we learn about a dataset $(\mathbf{x}_i)$ by just looking at it? (ie. without any labelled information y_i)



3. Reinforcement Learning

How can an agent interact with its environment (the data) to get maximum reward (eg. game playing, robots learning to walk)?

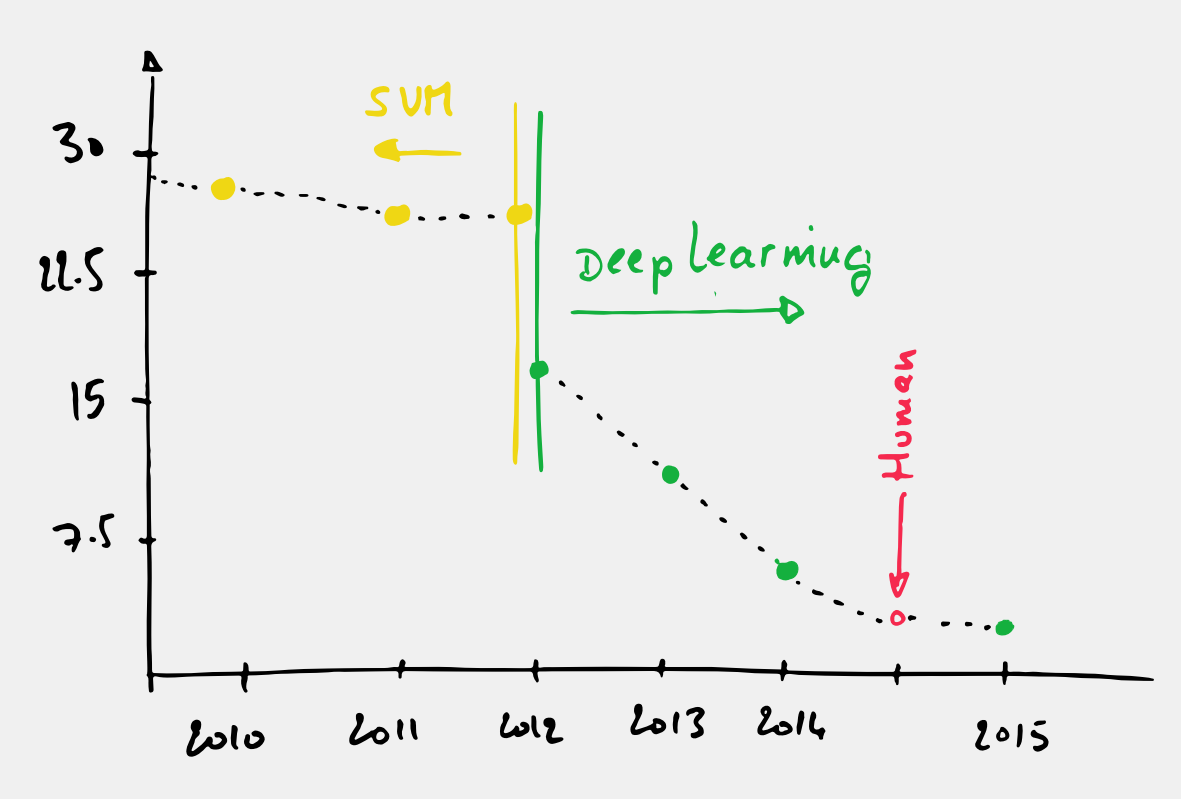


Deep Learning has made major breakthroughs in all three fields.

Deep Learning Successes

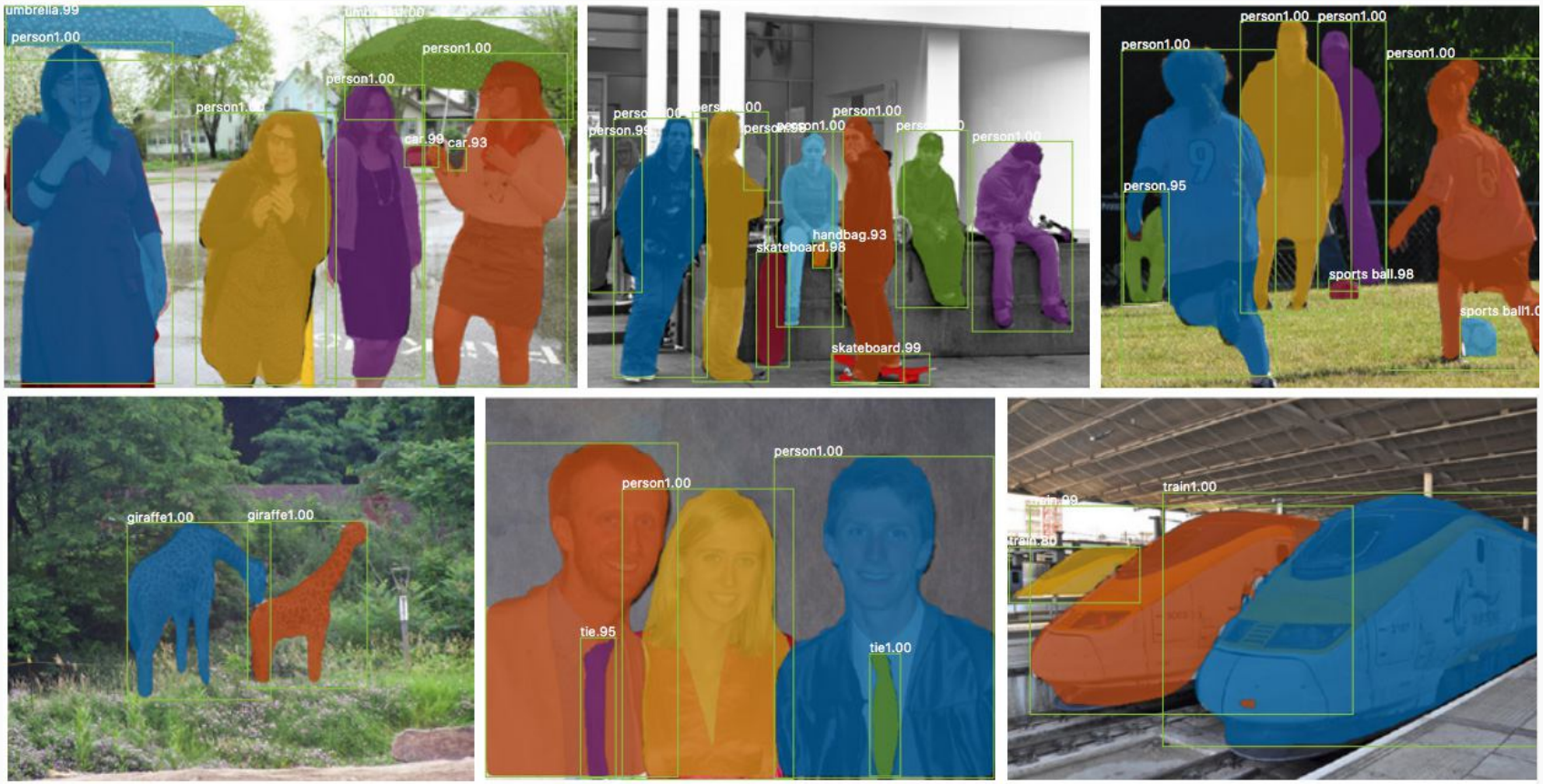
Image Recognition is one of the core applications of Computer Vision. ImageNet [www.image-net.org] runs an annual challenge where software programs compete to correctly classify and detect objects and scenes in images.

The error rate in object recognition for that challenge has massively dropped since the introduction of deep neural networks in 2012 [1]. Machines can now do better than humans.



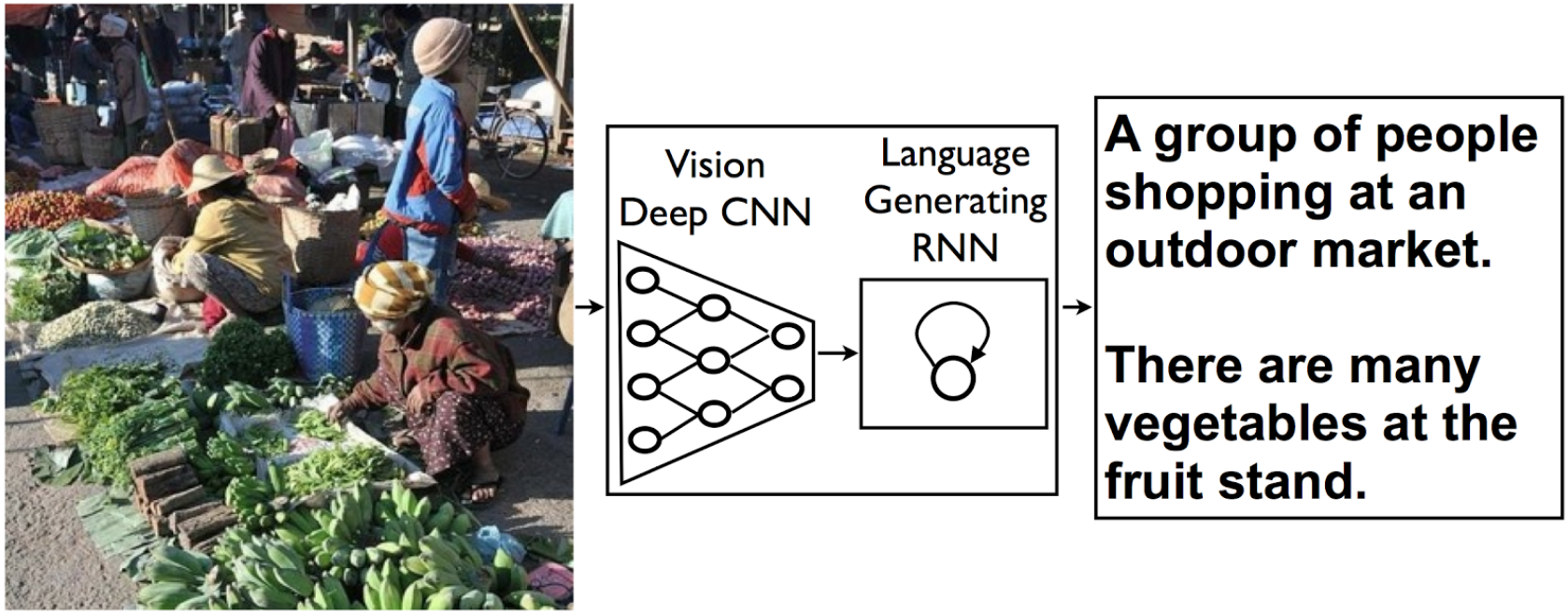
[1] ImageNet Classification with Deep Convolutional Neural Networks
A Krizhevsky, I Sutskever, G Hinton, 2012 [https://goo.gl/wxen2Y]

These neural nets have then been adapted to achieve state of the art in Scene Understanding.



[1] Mask R-CNN
Kaiming He et al., 2017 [https://arxiv.org/abs/1703.06870]

Image models combined with language models make it possible to automatically generate captions from images.



Google Research Blog (2014) [https://goo.gl/U88bDQ]

All major tech companies have changed their machine translation systems to use Deep Learning.

Google used to average a yearly 0.4% improvement on their machine translation system. Their first attempt at using Deep Learning yielded an overnight 7% improvement! More than in an entire lifetime!

Several years of handcrafted development could not match a single initial deep learning implementation.

New York Times, “The Great AI Awakening” (2016) [https://goo.gl/DPYp6d]

Note that since then, Large Language Models (LLM) have revolutionised text processing.

These models contain hundreds of billions of parameters and have been trained to predict text on a extremely large corpus of Internet sources, made of hundreds of billion words, and sometimes dozen of languages.

GPT-3 [1] (2020) and is perhaps one of the most famous ones and has been adopted in hundreds of applications, ranging from grammar correction, translation, summarisation, Chat Bots, text generation, etc.

GTP-3 [https://openai.com/blog/gpt-3-apps/]

[1] Language Models are Few-Shot Learners
T. Brown et al., 2020 [https://arxiv.org/abs/2005.14165]

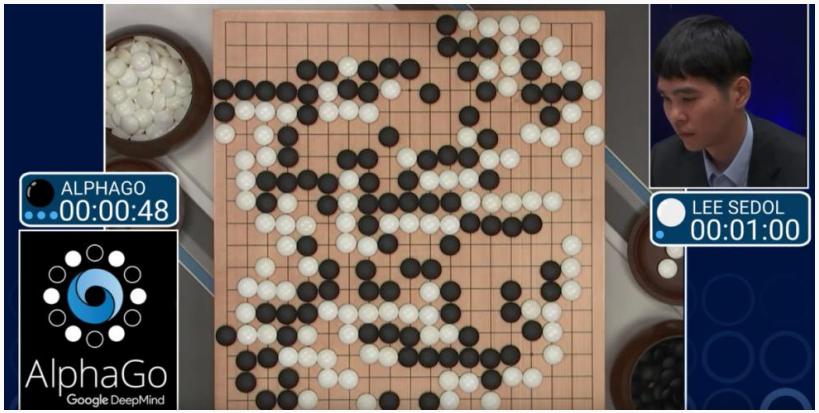
Deep Learning has become the universal language for dealing with any content driven application.

For instance, in Skype Translator (2014), speech recognition, automatic machine translation and speech synthesis tasks are combined, with Deep Learning acting as the glue that holds these elements together.

Skype demo [https://www.youtube.com/embed/NhxCg2PA3ZI?start=0]
Microsoft blog post [https://goo.gl/eAuPcS]

Deep learning has also been introduced in reinforcement learning to solve complex sequential decision making problems.

Recent successes include:
playing old Atari computer games, programming real world Robots and beating humans at Go.



demo: Robots Learning how to walk (2017) https://www.youtube.com/hx_bgoTF7bs

DeepMind https://goo.gl/3TcCNA

demo: AI-Driven, Physics-Based Character Animation (2022) https://nv-tlabs.github.io/ASE/

Reasons of a Success

Neural Networks have been around for decades. But is only now that it surpasses all other machine learning techniques.

Deep Learning is now a disruptive technology that has been unexpectedly taking over operations of technology companies around the world.

“The revolution in deep nets has been very profound, it definitely surprised me, even though I was sitting right there.”

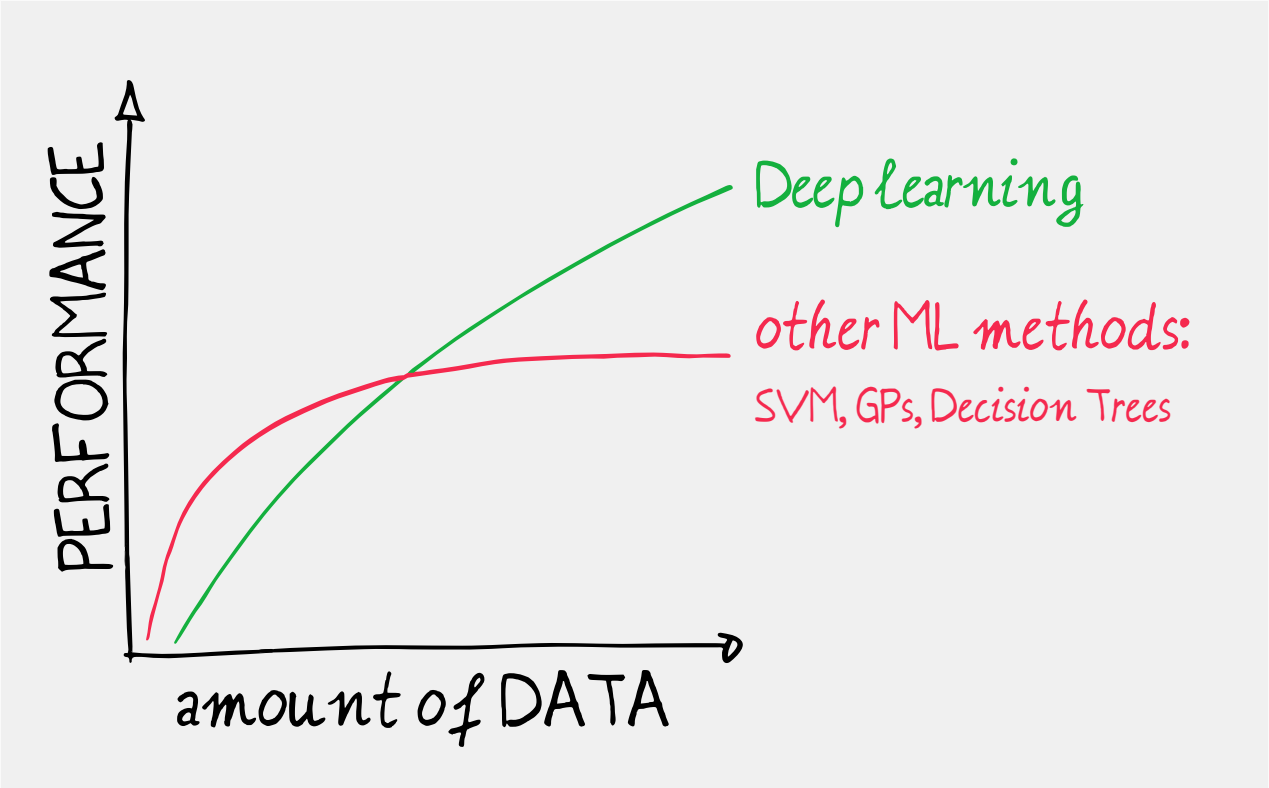
— Sergey Brin, Google co-founder

Reasons of a Success

Scale

Why now?

Because Deep Learning does scale.



Reasons of a Success

Scale

Neural Nets are the only ML technique whose performance **scales efficiently with the training data size**. Other ML popular techniques just can't scale that well.

The advent of **big databases**, combined with cheaper **computing power** (Graphic Cards), meant that Deep Learning could take advantage of all this, whilst other techniques stagnated. Instead of using thousands of observations, Deep Learning can take advantage of billions.

The tipping point was 2012 in Computer Vision and around 2014 in Machine Translation.

Reasons of a Success

Simplicity

Deep Learning offers a (relatively) simple framework to define and parameterise pretty much any kind of numerical method and then optimise it over massive databases.

Reasons of a Success

Universality

The universality of Deep Learning is actually astonishing. The same framework can be used in many fields. Which means that the same framework can tackle extremely complex applications. We can now combine information coming from pretty much any signal, eg. audio, text, images, stock market, twitter feeds, etc.

Reasons of a Success

Democratisation

Deep Learning offers a (relatively) simple framework to define and parameterise pretty much any kind of numerical method and then optimise it over massive databases.

Good programmers can train state of the art neural nets without having done 10+ years of research in the domain.

It is an opportunity for start-ups and it has become a ubiquitous tool in tech companies.

Reasons of a Success

Global Reach

It has been applied successfully to many fields of research, industry and society:

self-driving cars, image recognition, detecting cancer, speech recognition, speech synthesis, machine translation, drug discovery and toxicology, customer relationship management, recommendation systems, bioinformatics, advertising, controlling lasers, etc.

> demo: Physics Simulation Prediction https://youtu.be/KfZFgSff9N8
>
> AlphaFold: predict the shape of a protein
> https://www.deepmind.com/research/highlighted-research/alphafold

Impact

Here is a question for you:

How long before your future job gets replaced by an algorithm?

Probably much sooner than you think. You might feel safe if you are an artist...

… but then again:

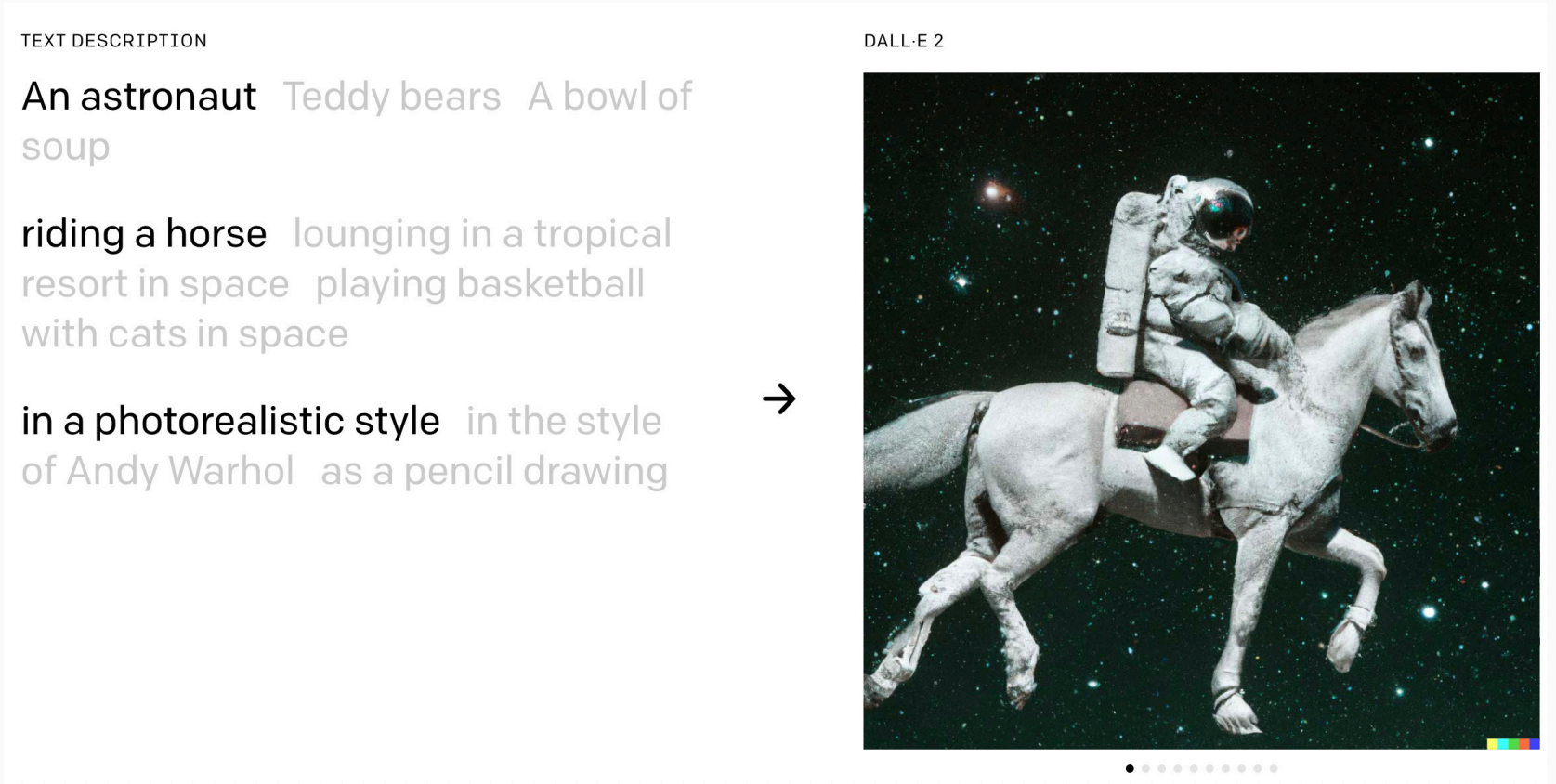
automatic style transfer [1]

[1] A Neural Algorithm of Artistic Style
L. Gatys, A. Ecker, M. Bethge, 2015 [https://arxiv.org/abs/1508.06576]

Does an AI need to make love to Rembrandt's girlfriend to make art? [https://goo.gl/gi7rWE]

Intelligent Machines: AI art is taking on the experts [https://goo.gl/2kfyXd]

... and now large neural networks are capable of combining text and images to produce incredibly creative and high quality pieces of art:



automatic image generation [2]

DALL·E 2 [https://openai.com/dall-e-2]

TEXT DESCRIPTION

An astronaut **Teddy bears** A bowl of soup

mixing sparkling chemicals as mad scientists shopping for groceries working on new AI research

as a 1990s Saturday morning cartoon as digital art in a steampunk style

DALL·E 2

automatic image generation [2]

DALL·E 2 [https://openai.com/dall-e-2]

Final Words

Yes, self-driving cars are not quite there yet...

Final Words

And, no, machines haven't become self-aware...

Google fires software engineer who claims AI chatbot is sentient

Company said Blake Lemoine violated Google policies and that his claims were 'wholly unfounded'

Google say LaMDA is simply a complex algorithm designed to generate convincing human language. Photograph: Andrew Kelly/Reuters

Final Words

... it is likely that Deep Learning-based self-driving systems will be good enough in coming years.

... and these large language models are really good and have really pushed the boundaries of what was possible in text generation and machine translation.

And we haven't yet hit the limits of what Deep Learning has to offer.

So make no mistake, this is a technological revolution.

The increased awareness of the societal and ethical concerns rised by the use at scale of these new technologies is further evidence of the significance of this revolution.

4C16: Course Structure

Course Content

Part 1. Machine Learning Fundamentals

In Week 1 - 4, we will cover

Least Squares: the root of all Machine Learning.
(feature mapping, over/under fitting, regularisation, maximum likelihood)

Logistic Regression: your first Neuron.
(linear classifier, cross-entropy , gradient descent optimisation)

Classic Classifiers: overview of classic machine learning algorithms.
(SVM, Decision Trees, Kernel Trick, Nearest-Neighbours)

Comparing Classifiers:
(ROC curves, confusion tables, F1 score)

Course Content

Part 2. Neural Net Fundamentals

Feedforward Neural Network
(network architecture, back-propagation, regularisation, vanishing gradients)

Convolutional Neural Network
(convolution layers, pooling, visualisation, knowledge transfer)

Autoencoders
(unsupervised learning, Variational AutoEncoders)

Recurrent Neural Network
(LSTM, word embedding, text processing)

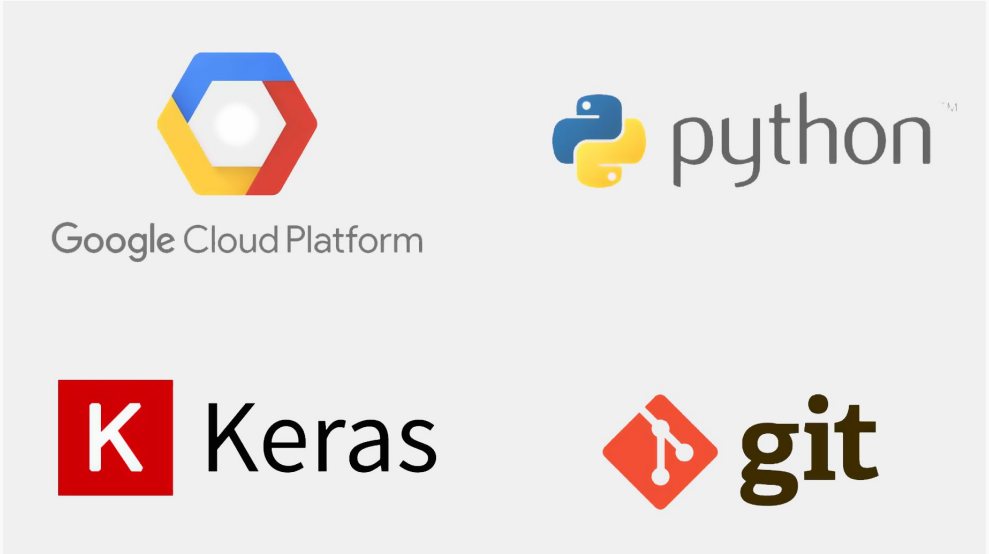
Transformers
(text processing, multimedia fusion)

Assignments [provisional]

Week 2	Least Squares lab	[2% mark]
Week 3	Logistic Regression lab	[2% mark]
Week 4	Classifiers lab	[2% mark]
Week 5	Feed Forward Neural Nets lab	[2% mark]
Week 6	Convolutional Neural Nets lab	[2% mark]
Week 8-10	lab	[5% mark]
Week 9-11	lab	[5% mark]
Midterm		[20% mark]
Exam		[60% mark]

Labs

We have developed a web based environment specially for you, so that you can learn best industry practices.



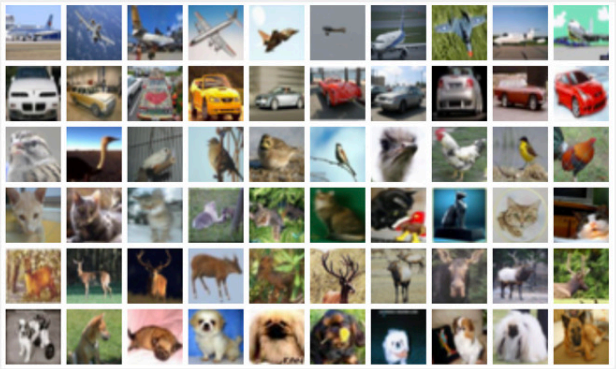
Labs

You will be programming in python 3 using Keras and TensorFlow. Everything will be running on the Google Cloud Platform or Colab, which gives you on-demand scalable computing resources.

Your coding environment will be a combination of shell/terminal, editor, and Jupyter notebook.

You will use Git to checkpoint your progress and for continuous feedback on lab assignments.

Labs



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[…]ake myself known, and first of all
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of such a serve and which it is a
spiritual in the still as a resern of will
as man […]
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Labs include image classification challenges for various DNN architectures.

We have adapted Udacity's self driving car simulator, so that you can train and operate an autonomous car using DNNs. [this may change]

you will implement a word-based RNN system to generate and detect fake Nietzsche's writings. [this may change]

Books & Resources

[1] Deep Learning (MIT press)
Ian Goodfellow et al.
[https://www.deeplearningbook.org]

[2] Machine Learning on Cousera
Andrew Ng
[https://www.coursera.org/learn/machine-learning]

[3] Neural Networks and Deep Learning
Michael Nielsen
[http://neuralnetworksanddeeplearning.com/]

[4] Curated list of links https://github.com/ChristosChristofidis/awesome-deep-learning

[5] Brandon Rohrer's YT channel https://www.youtube.com/user/BrandonRohrer

[6] Siraj Raval's YT channel https://www.youtube.com/channel/UCWN3xxRkmTPmbKwht9FuE5A