



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

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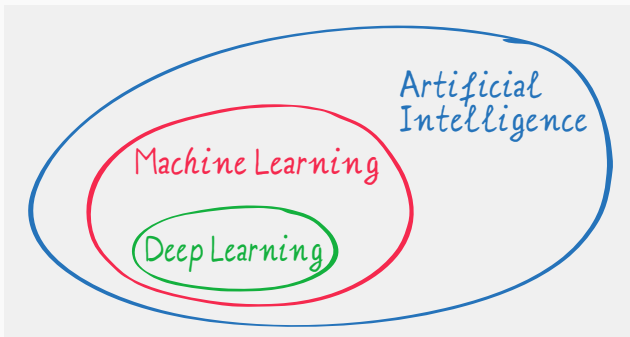
This module is an introduction to Machine Learning and especially **Deep Neural Nets**, which are disrupting all aspects of society today.

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.



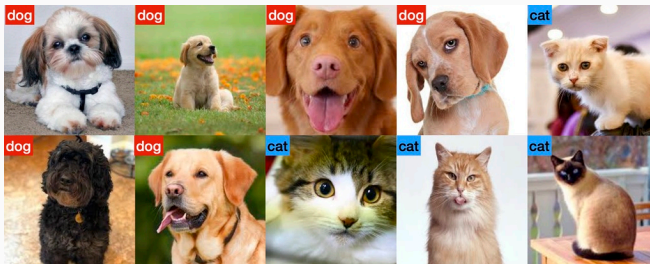
The recent quantum leap in machine learning has solely been driven by deep learning successes.

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

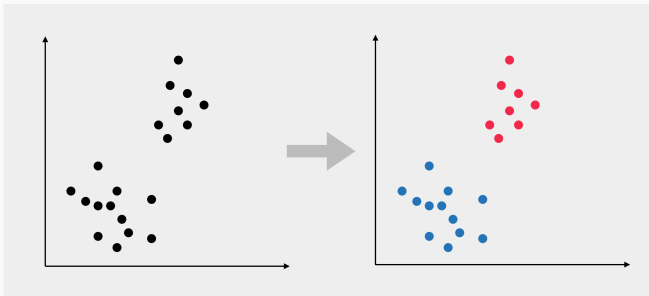
We have a labelled dataset  $(\mathbf{x}_i, y_i)_{i \in \{1..n\}}$  containing features  $\mathbf{x}_i$  (eg. the image pixels) and outcomes  $y_i$  (eg. cat=0/dog=1 label).



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

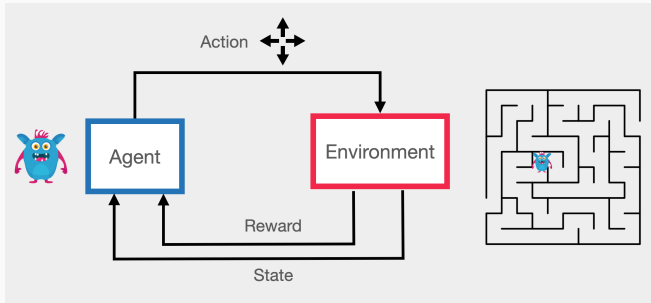
## 2. Unsupervised Learning

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.



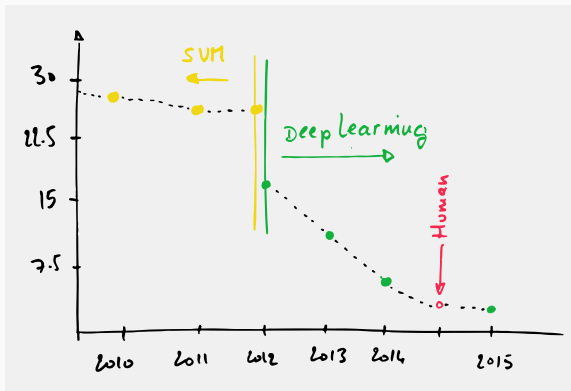
# Deep Learning Successes

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**Image Recognition** is one of the core applications of Computer Vision. ImageNet [[www.image-net.org](http://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>]

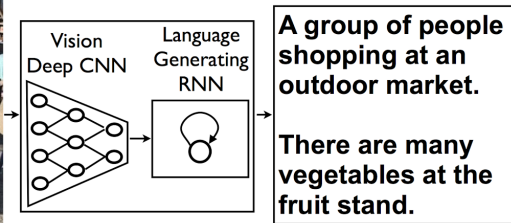
These neural nets have then been adapted to achieve state of the art in **Scene Understanding**.



[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.



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>]

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/NhxKg2PA3ZI?start=0>]

Microsoft blog post [<https://goo.gl/eAuPcS>]

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 an 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 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](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

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

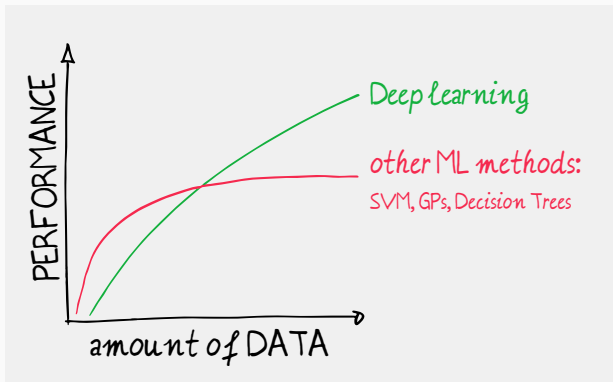
Deep Learning is now a **disruptive** technology that has been unexpectedly taking over operations of technology companies around the world.

“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

Why now?

Because Deep Learning does 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.

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

By adopting an automated optimisation approach to tuning algorithms, Deep Learning is able to surpass hand-tailored algorithms of skilled researchers.

It offers a systematic approach when before algorithms took years of human efforts to design.

# Reasons of a Success

## Democratisation

Deep Learning is a (relatively) simple framework.

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:

TEXT DESCRIPTION

An astronaut Teddy bears A bowl of soup

riding a horse lounging in a tropical resort in space playing basketball with cats in space

in a photorealistic style in the style of Andy Warhol as a pencil drawing



DALL-E 2



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>]

## 4C16: Course Structure

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# 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**

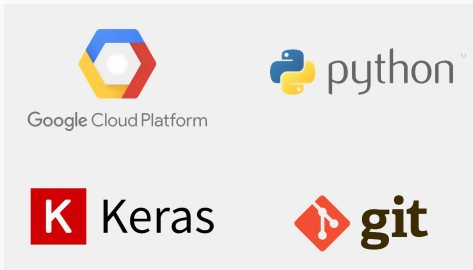
(text processing, multimedia fusion)

## 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]
<i>Midterm</i>		[20% mark ]
<i>Exam</i>		[60% mark ]



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



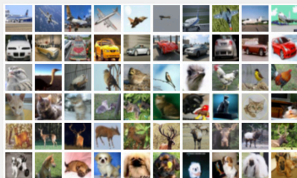
# Labs

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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[...mplify the manifold,  
to overlook or repulsion of the struction  
of the serve and instinct is enjoyments of  
the structing the same and  
distinction of the [...]
```

```
-----  
[...ake myself known, and first of all  
learner with the sense of the highterness  
of such a serve and which it is a  
spiritual in the still as a resern of will  
as man [...]
```

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 Coursera

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>