

Fundamentals of Machine Learning

Basic concepts and historical context that led to the success of deep learning

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W2024



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Outline

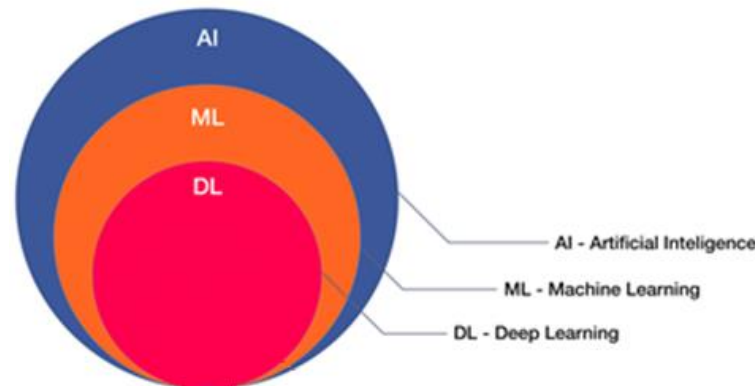
- Learning Goals
- Artificial intelligence (AI), machine learning (ML) and deep learning (DL)
 - Definitions
 - Historical context
- Fundamental ML concepts
- Summary

Learning Goals

- Explain the difference between AI, ML, and DL
- Explain the historical context that led to the success of DL
- Introduce basic ML concepts

Artificial Intelligence (AI) Machine Learning (ML) and Deep Learning (DL)

- AI: the broad discipline of creating intelligent machines
- ML: refers to systems that can learn from experience
- DL: refers to systems that learn from experience on large data sets
- Neural Networks (NN): models of human neural networks that are designed to help computers learn




What is Machine Learning?


- Algorithms to parse data, learn from it, and make determinations or predictions about something in the world
- Build models by training with data
- Three aspects:
 - **Data** -> engineer or learn features? how to set the experiment?
 - **Model**-> which model is best? Many times arbitrary
 - **Cost function minimization** -> set model parameters
- Concerns: interpretability, explainability (*i.e.*, black boxes), generalizability

Traditional ML

- Feature engineering
- “Simpler models” -> less parameters to be learned

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1M} \\ x_{21} & x_{22} & \dots & x_{2M} \\ x_{31} & x_{32} & \dots & x_{3M} \\ \dots & \dots & \dots & \dots \\ x_{N1} & x_{N2} & \dots & x_{NM} \end{bmatrix}$$


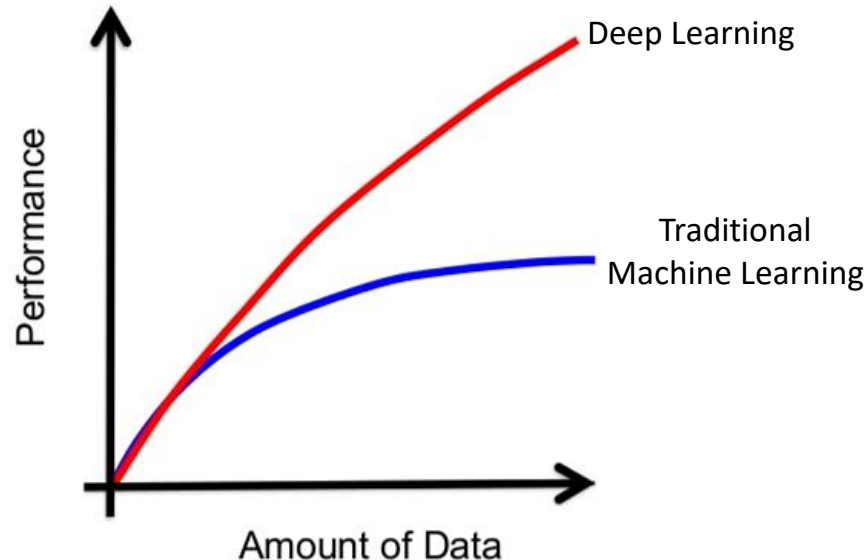
N samples with M features

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \dots \\ y_N \end{bmatrix}$$


Labels

Deep Learning (DL)

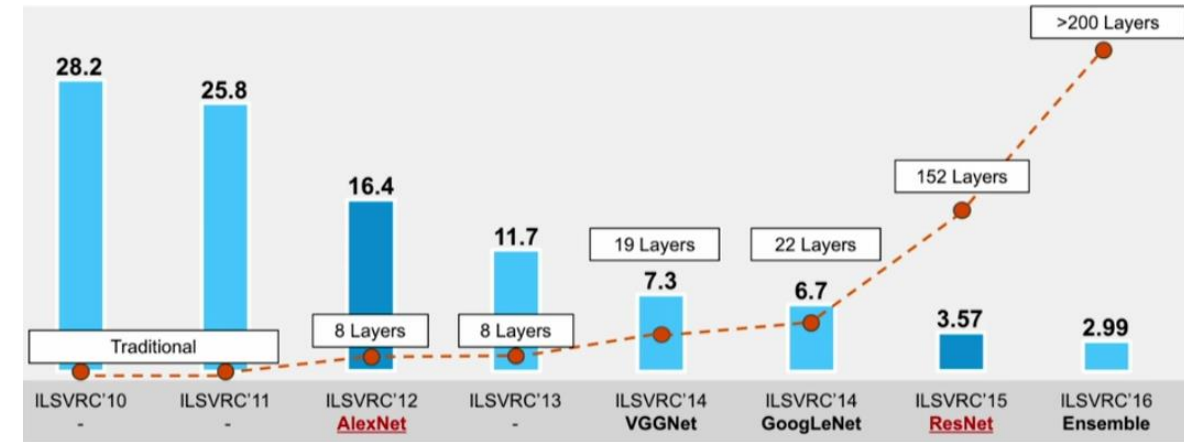
- DL is a data-driven modeling approach, which “learns the features”
 - But which features?
- Complex models with (b)illions of parameters that need to be tuned



ImageNet Challenge

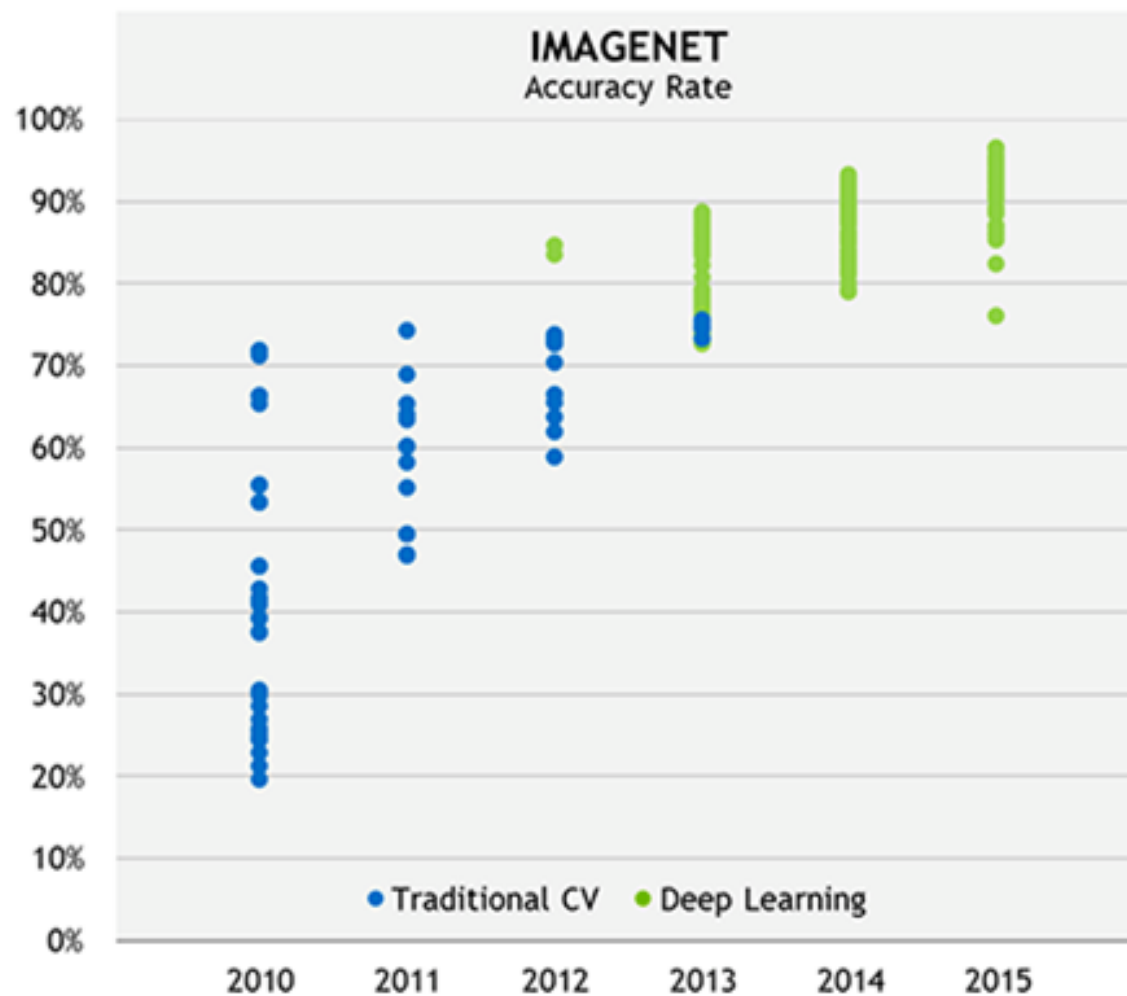


- ImageNet is a large scale object classification challenge
- >14,000,000 annotated images
- >20,000 classes



- In 2012 teams started using graphics processing units (GPUs)


ImageNet Challenge

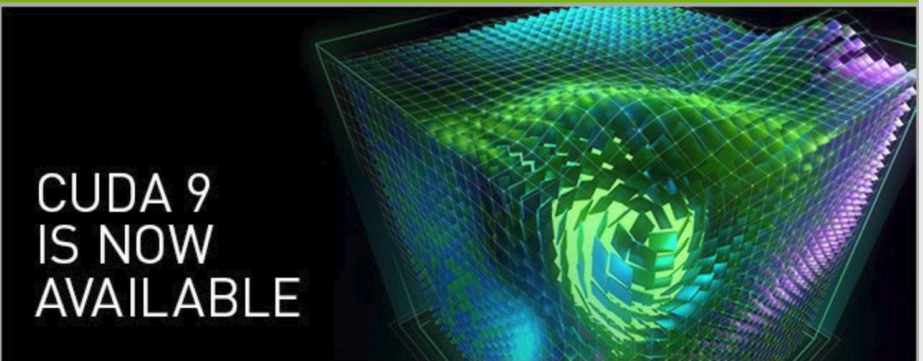


GPU/TPU Computing

- Hardware and software improvements
- GPUs with more cores and more memory
- Optimized parallel computing platforms



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Large Datasets

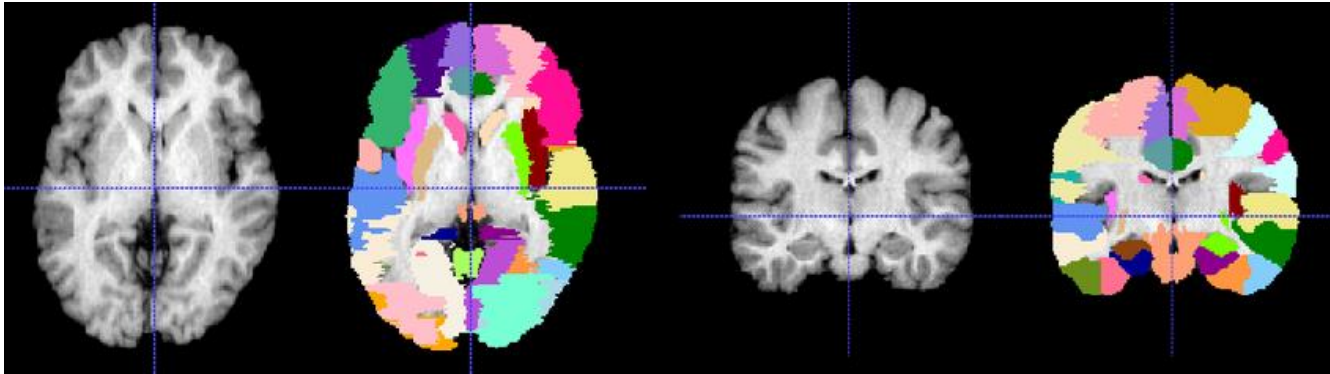
airplane
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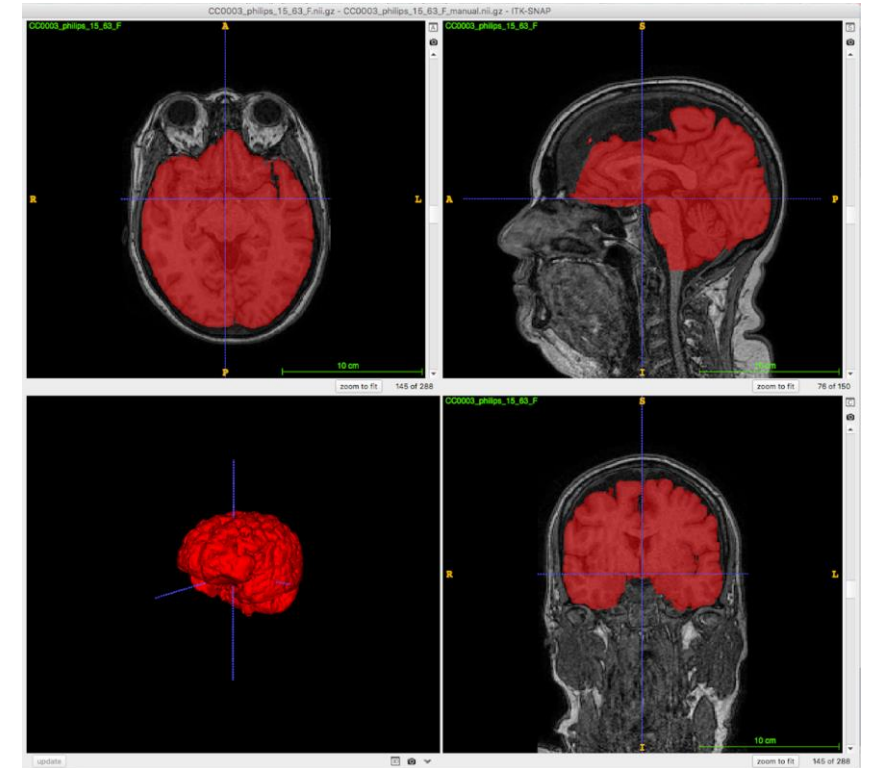
CIFAR-10



MNIST



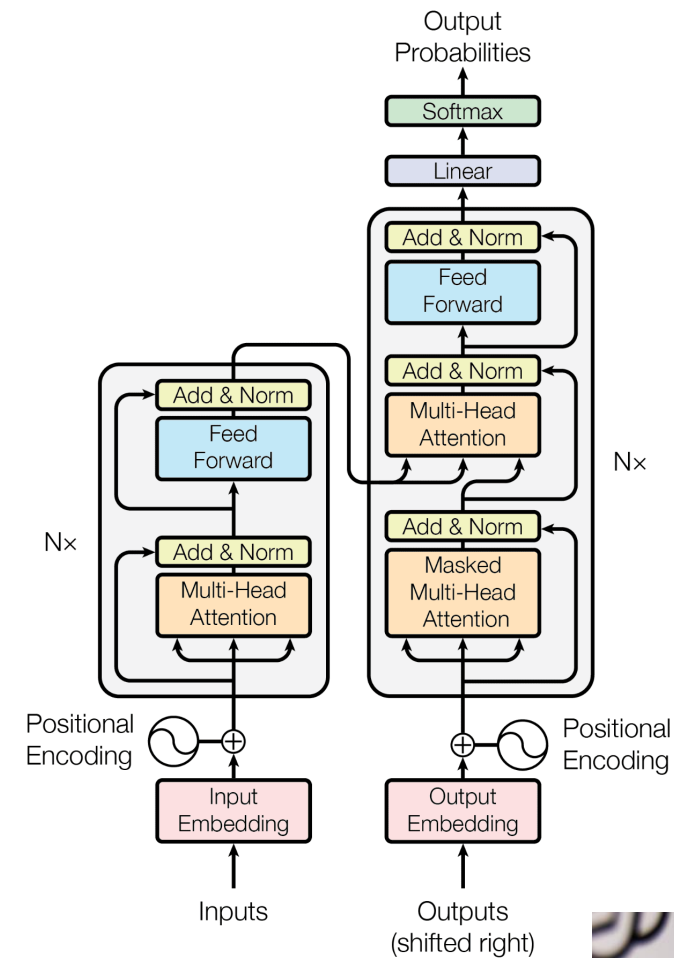
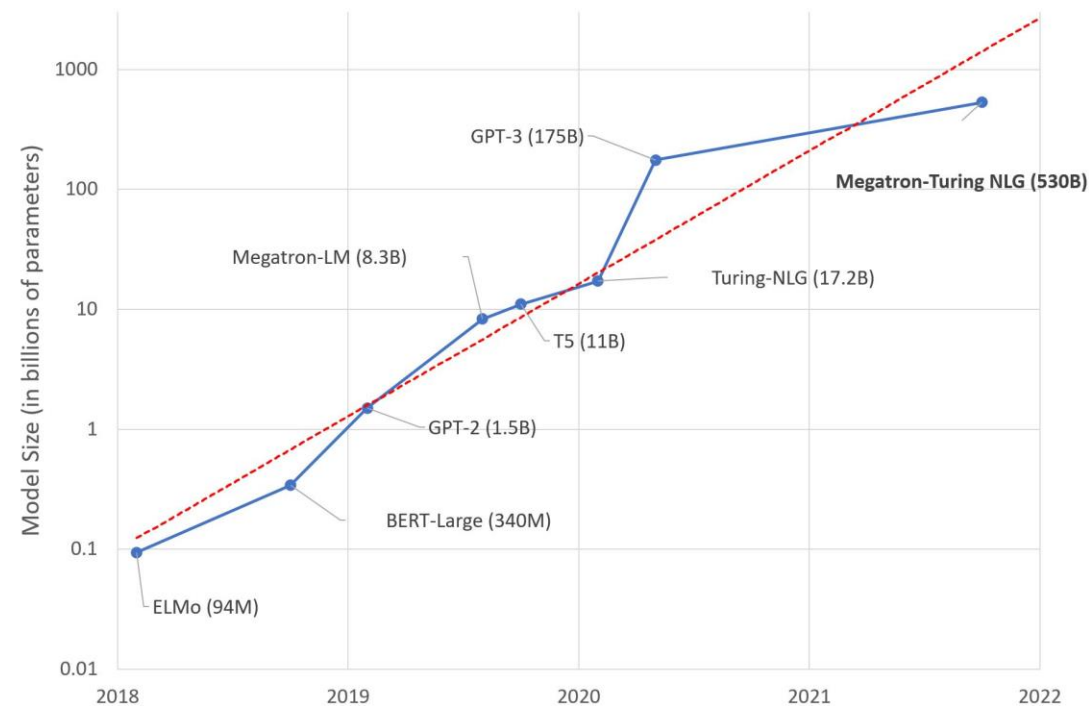
LPBA40



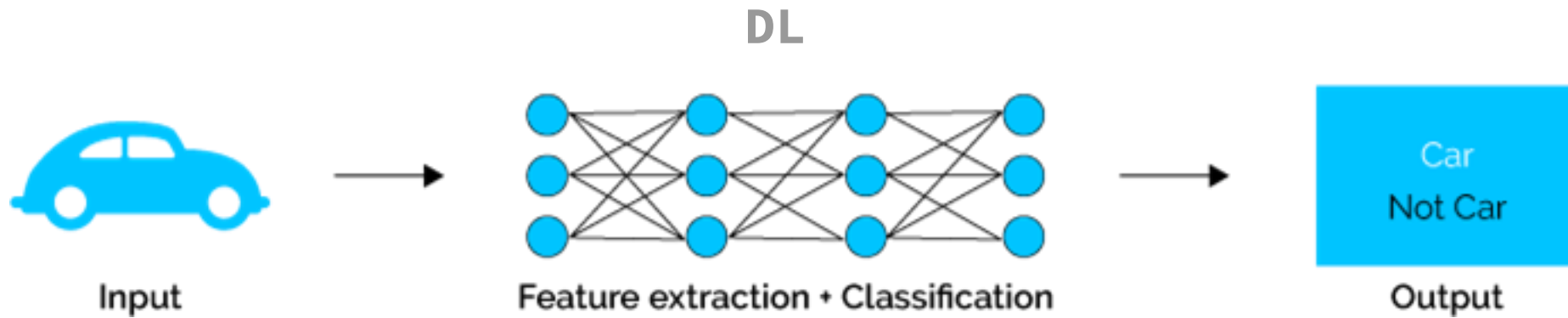
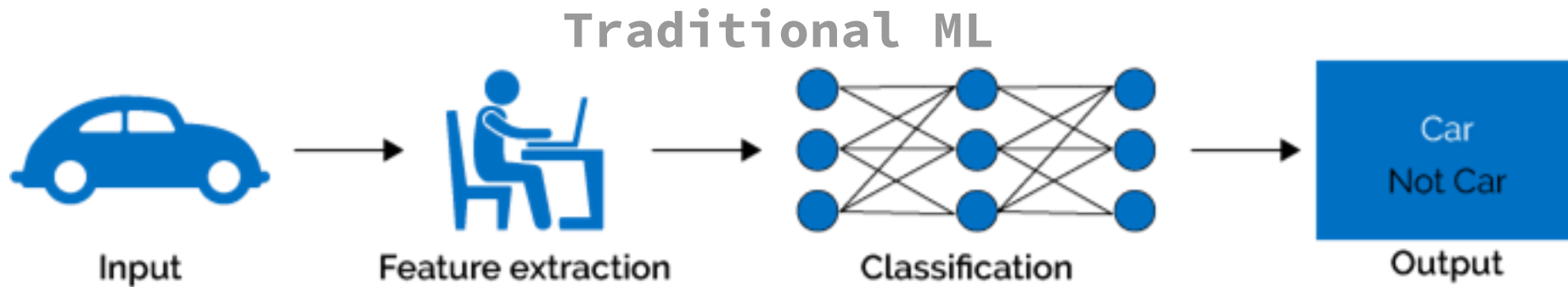
Calgary-Campinas-359

<https://sites.google.com/view/calgary-campinas-dataset/home>

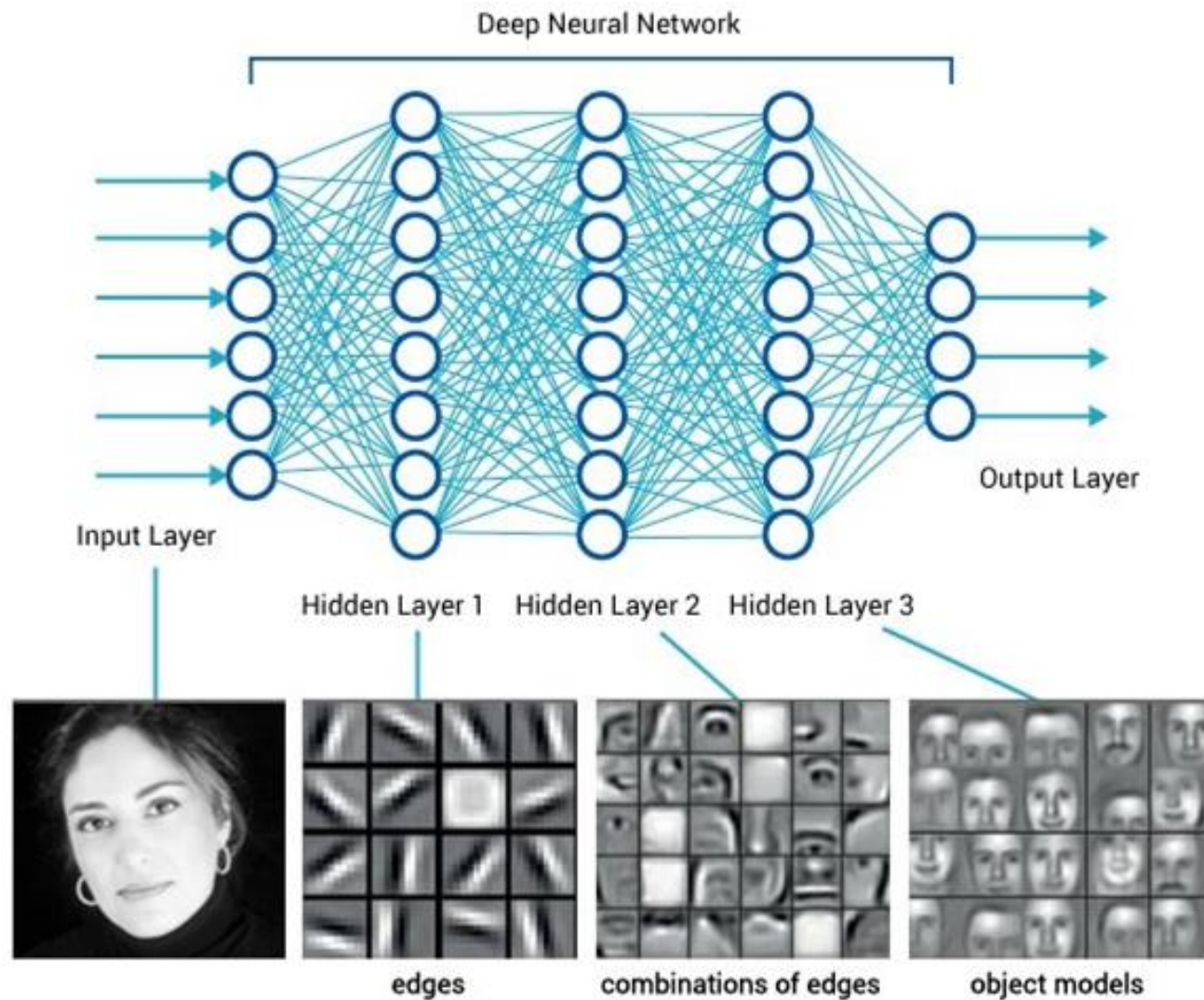
Large Language Models



Traditional ML versus DL



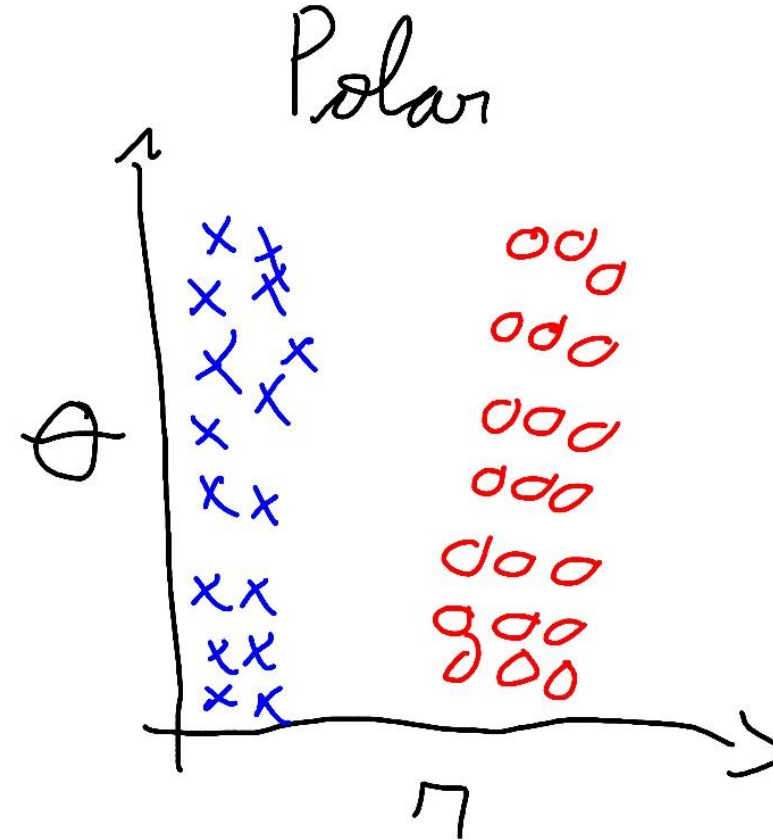
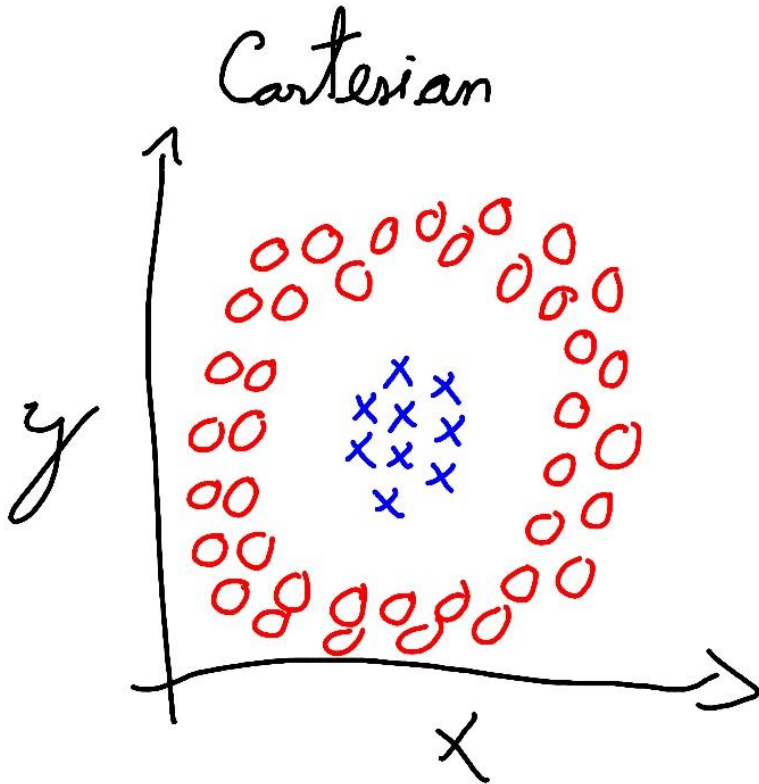
DL Hierarchy of Concepts



It is all about data representation....

- Roman numbers arithmetic:
 - $\text{CCCXXVII} + \text{CXXIII} = ?$ **CDL**
- Arabic numbers arithmetic:
 - $327 + 123 = ?$ **450**

It is all about data representation....



Scientific Community is Paying Attention...

nature
International journal of science

Review Article | Published: 27 May 2015

Deep learning





Yann LeCun , Yoshua Bengio & Geoffrey Hinton


Nature **521**, 436–444 (28 May 2015) | [Download Citation](#) 

nature
International journal of science

Letter | Published: 25 January 2017

Dermatologist-level classification of skin cancer with deep neural networks

Andre Esteva , Brett Kuperl , Roberto A. Novoa , Justin Ko, Susan M. Swetter, Helen M. Blau & Sebastian Thrun 

Nature **542**, 115–118 (02 February 2017) | [Download Citation](#) 

nature
International journal of science

Letter | Published: 21 March 2018

Image reconstruction by domain-transform manifold learning

Bo Zhu, Jeremiah Z. Liu, Stephen F. Cauley, Bruce R. Rosen & Matthew S. Rosen 

Nature **555**, 487–492 (22 March 2018) | [Download Citation](#) 

Supervised x Unsupervised Learning

- **Supervised:** the data present associated outputs (labels/classes)
- **Unsupervised:** no labels are given to the learning algorithm
 - The goal is to discover groups in the data (clustering) or to determine the distribution of data within the input space (density estimation)

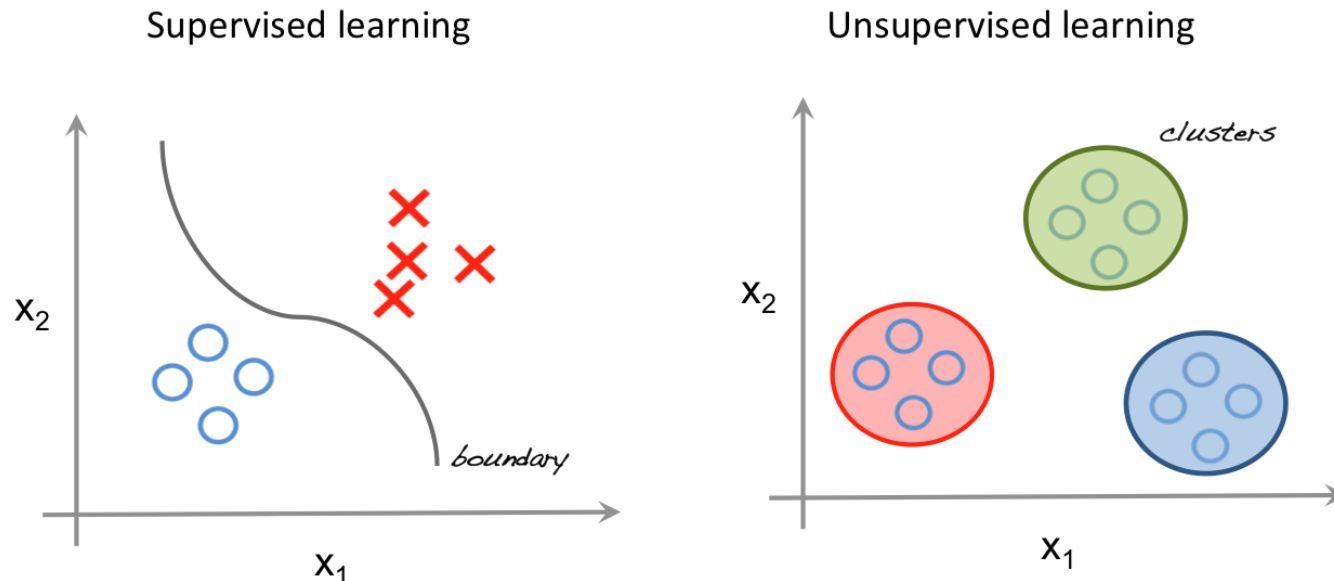
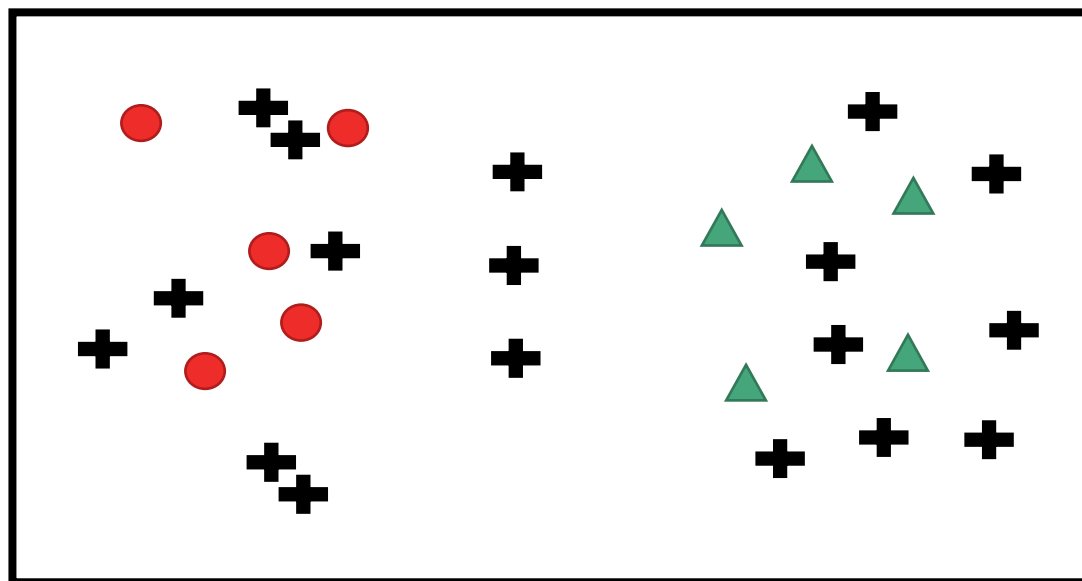


Figure: <http://beta.cambridgespark.com/courses/jpm/01-module.html>

Semi-Supervised Learning

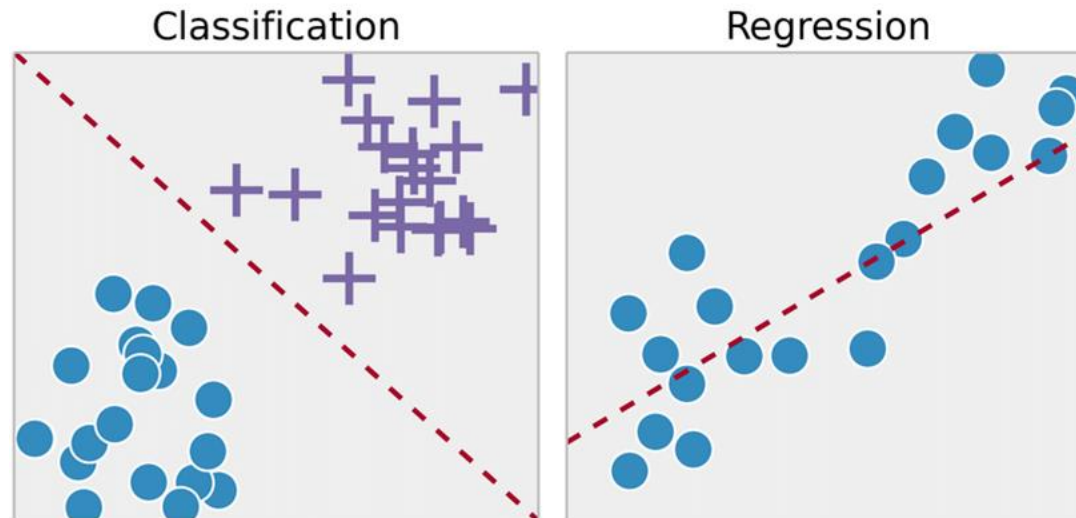
- **Semi-supervised learning** combines a small amount of labeled data with a large amount of unlabeled data during training.
 - Falls in between supervised and unsupervised learning
 - It is a case of weak supervision



- Class A
- ▲ Class B
- ✚ Unlabeled data point

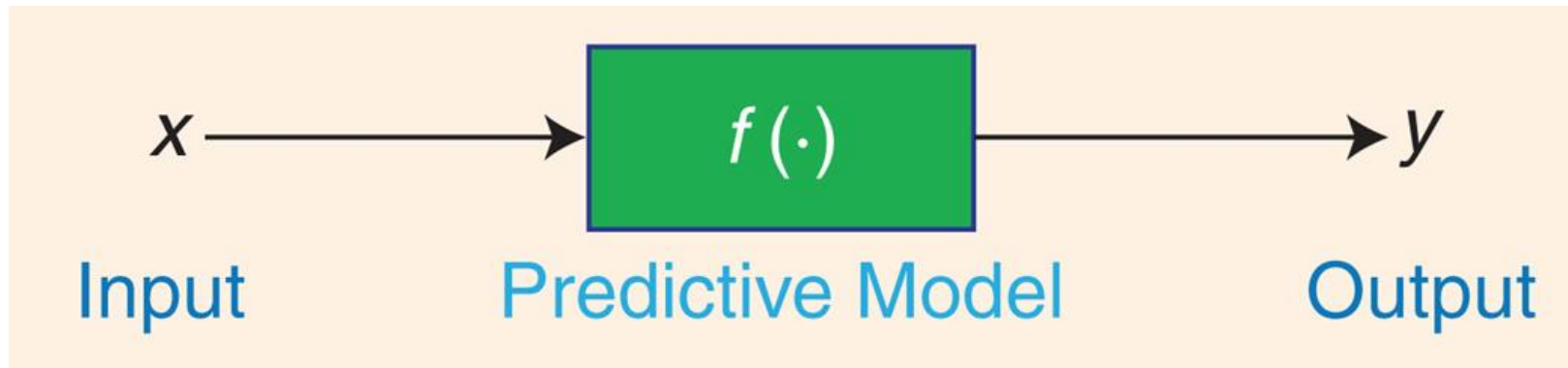
Classification × Regression

- **Classification** refers to decision among a discrete and typically small set of choices (*e.g.*, identifying a tumor as malignant or benign)
- **Regression** refers to estimating a continuous output variable (*e.g.*, diagnostic assessment of disease severity)



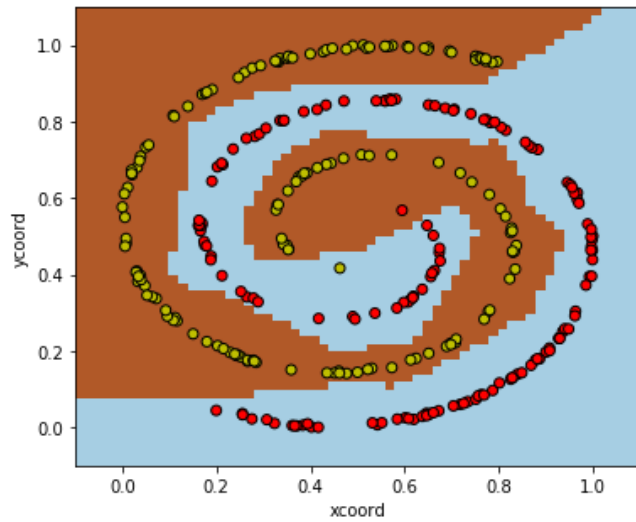
Supervised Classification

- Predictive model represents the assumed relationship between input variables in \mathbf{x} and output variable $\mathbf{y} \rightarrow \mathbf{y} = f(\mathbf{x})$
 - the output of the predictive model can be a vector
- \mathbf{x} is composed of M variables (called features), so that $\mathbf{x}_i \in \mathbb{R}^M$
- \mathbf{y} can be a vector (e.g., in multi-class classifiers)

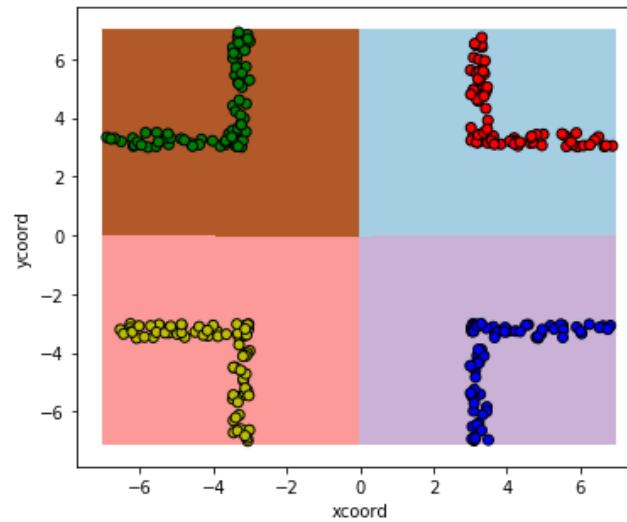


Binary x Multi-class x Multi-label Classification

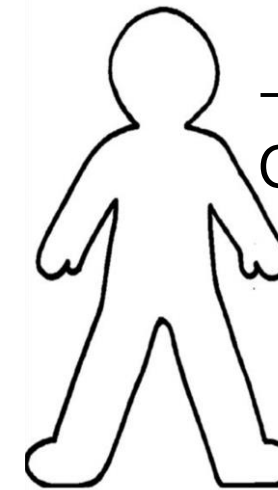
- **Binary:** 2 possible classes (labels).
- **Multi-class:** C ($C > 2$) possible classes.
- **Multi-label:** A sample can belong to more than one class.



Binary



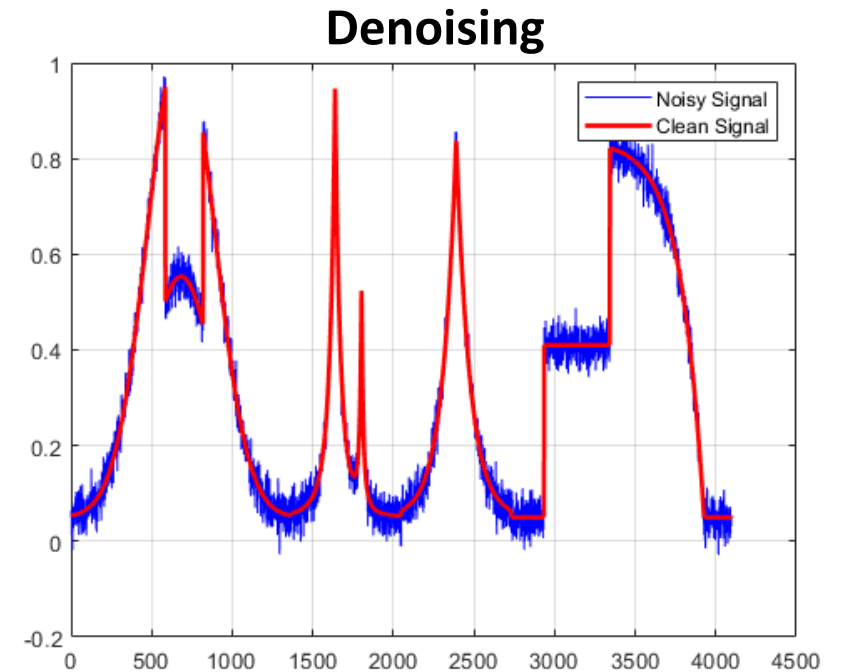
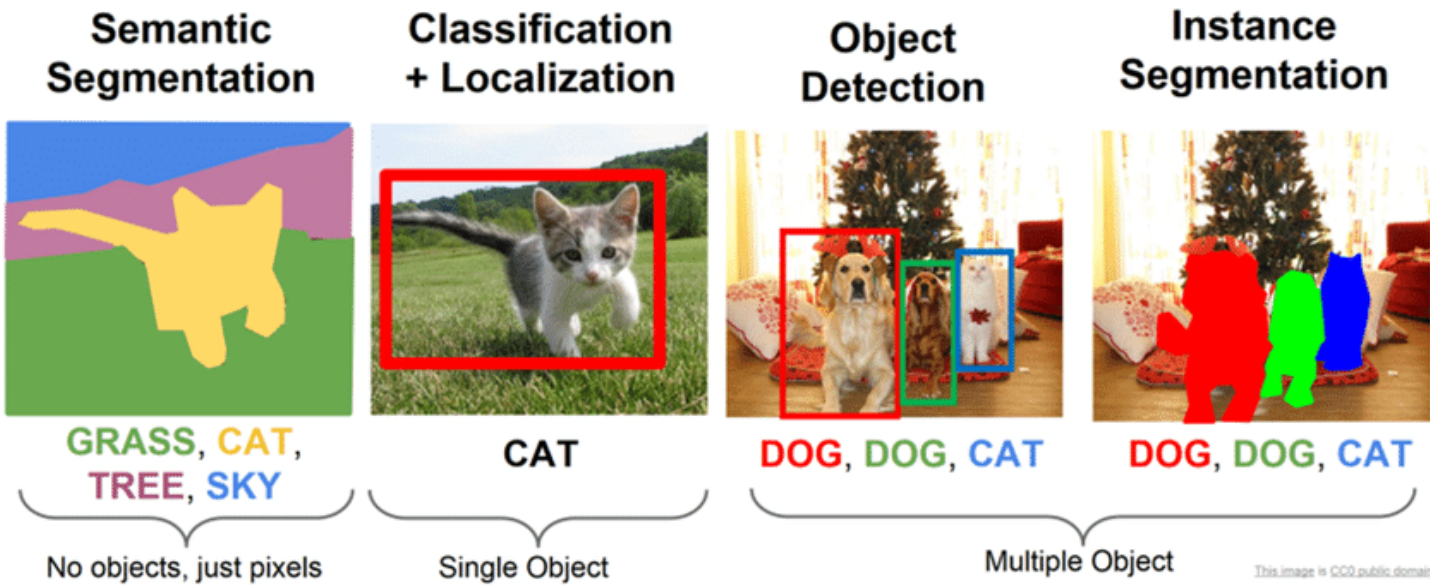
Multi-class



-> Class A and
Class B

Multi-label

Types of Problems



Domain Shift

- Domain shift occurs when the source data distribution is different (but related) to the target data distribution



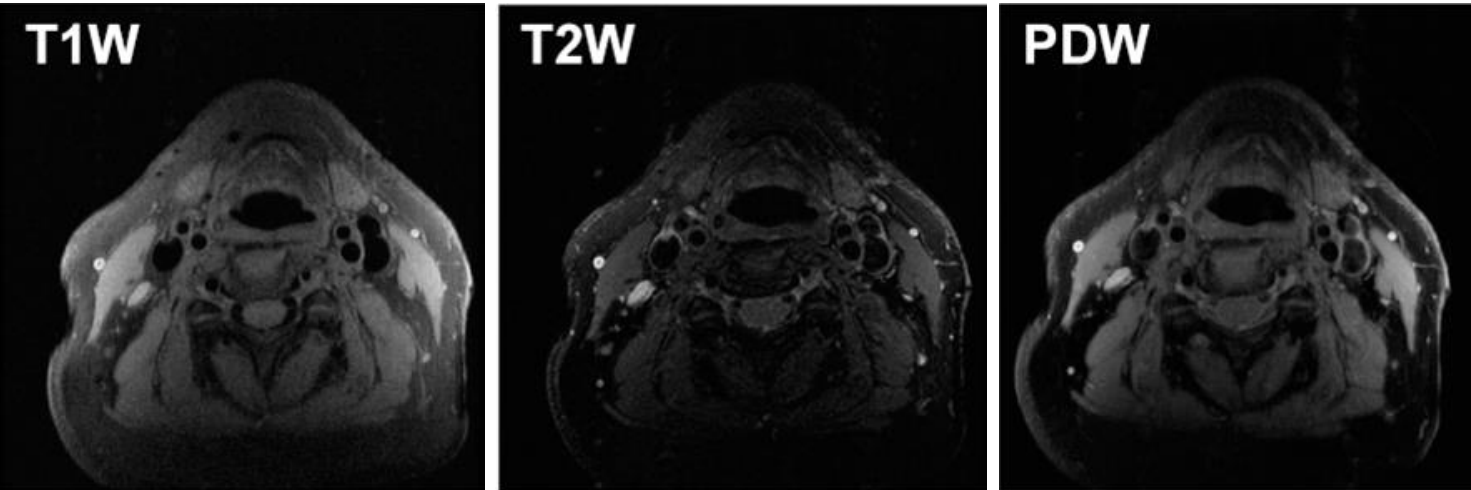
Source domain



Target domain

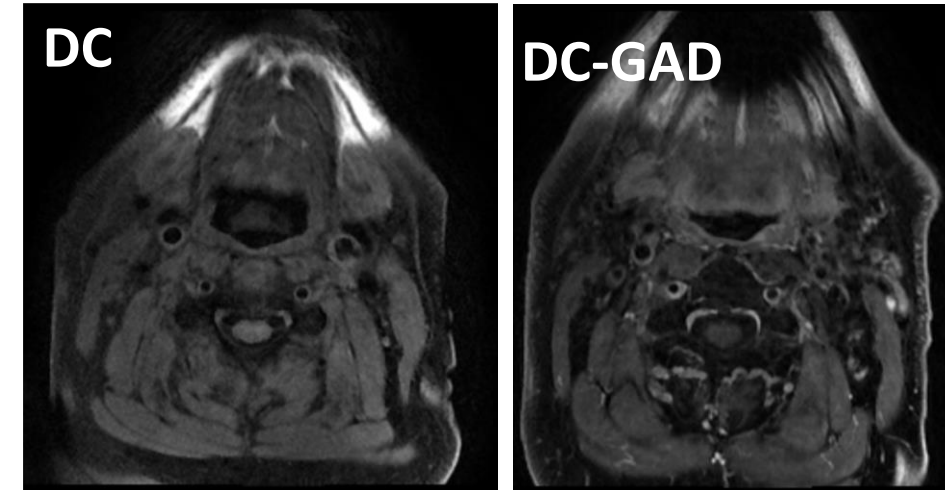
Domain Shift

AIM-HIGH Study



- The carotid arteries were manually annotated at the time of the study

CARDIS Study



- Leverage AIM-HIGH annotated data to create a segmentation model for the data being collected at CARDIS study

Summary

- $DL < ML < AI$
- The success of DL methods came with the development in hardware (GPUs/TPUs), software and availability of data (ImageNet)
- DL models can learn the features from the data
- DL models performance scales better with the amount of data available

Thanks!