# Fundamentals of Machine Learning

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

**Roberto Souza**
Assistant Professor
Electrical and Computer Engineering
Schulich School of Engineering

F2024

UNIVERSITY OF CALGARY

# Outline

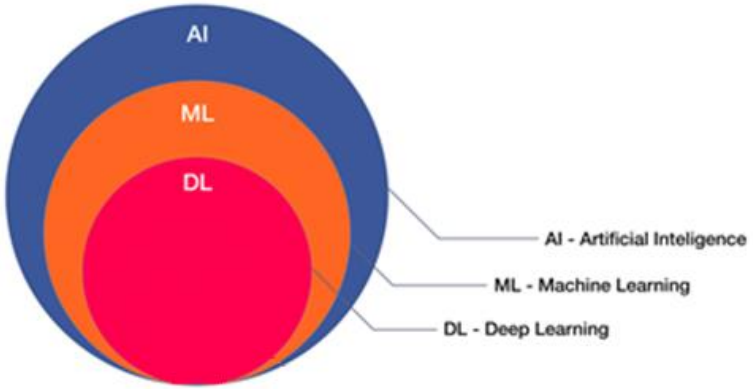
- Learning Goals
- Artificial intelligence (AI), machine learning (ML) and deep learning (DL)
  - Definitions
  - Historical context
- Fundamental ML concepts
- Summary

# 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

$$X = \underbrace{\begin{bmatrix} x_{11} & x_{12} & \dots & x_{1M} \\ x_{21} & x_{22} & \dots & x_{2M} \\ x_{31} & x_{32} & \dots & x_{3M} \\ \dots & \dots & \dots & \dots \\ x_{N1} & x_{N2} & \dots & x_{NM} \end{bmatrix}}_{\text{N samples with M features}}$$

$$Y = \underbrace{\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \dots \\ y_N \end{bmatrix}}_{\text{Labels}}$$

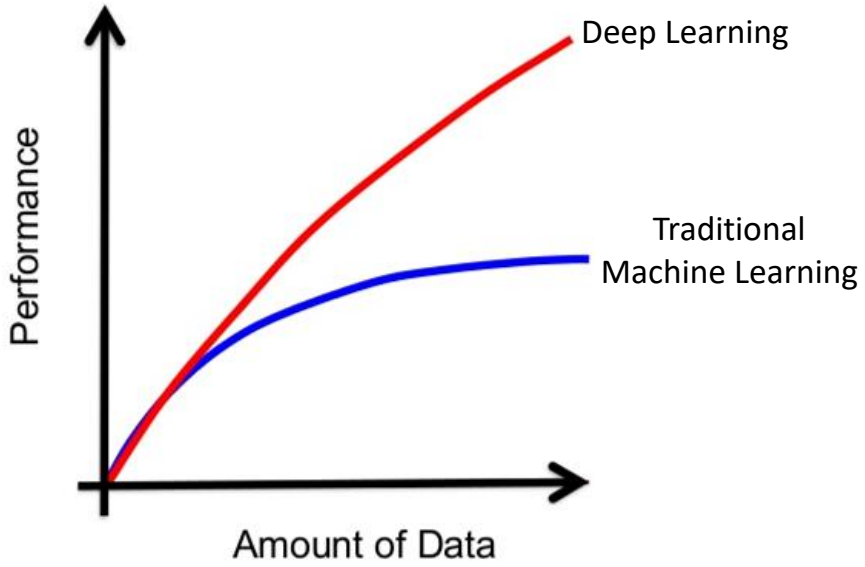


6

# Deep Learning (DL)

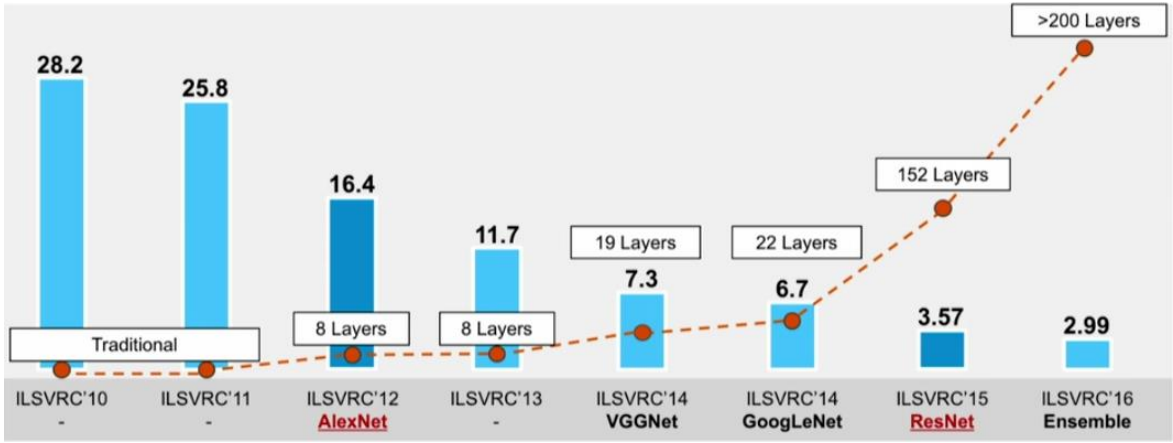
- DL is a data-driven modeling approach, which “learns the features”
  - But which features?

- Complex models with (b)millions of parameters that need to be tuned



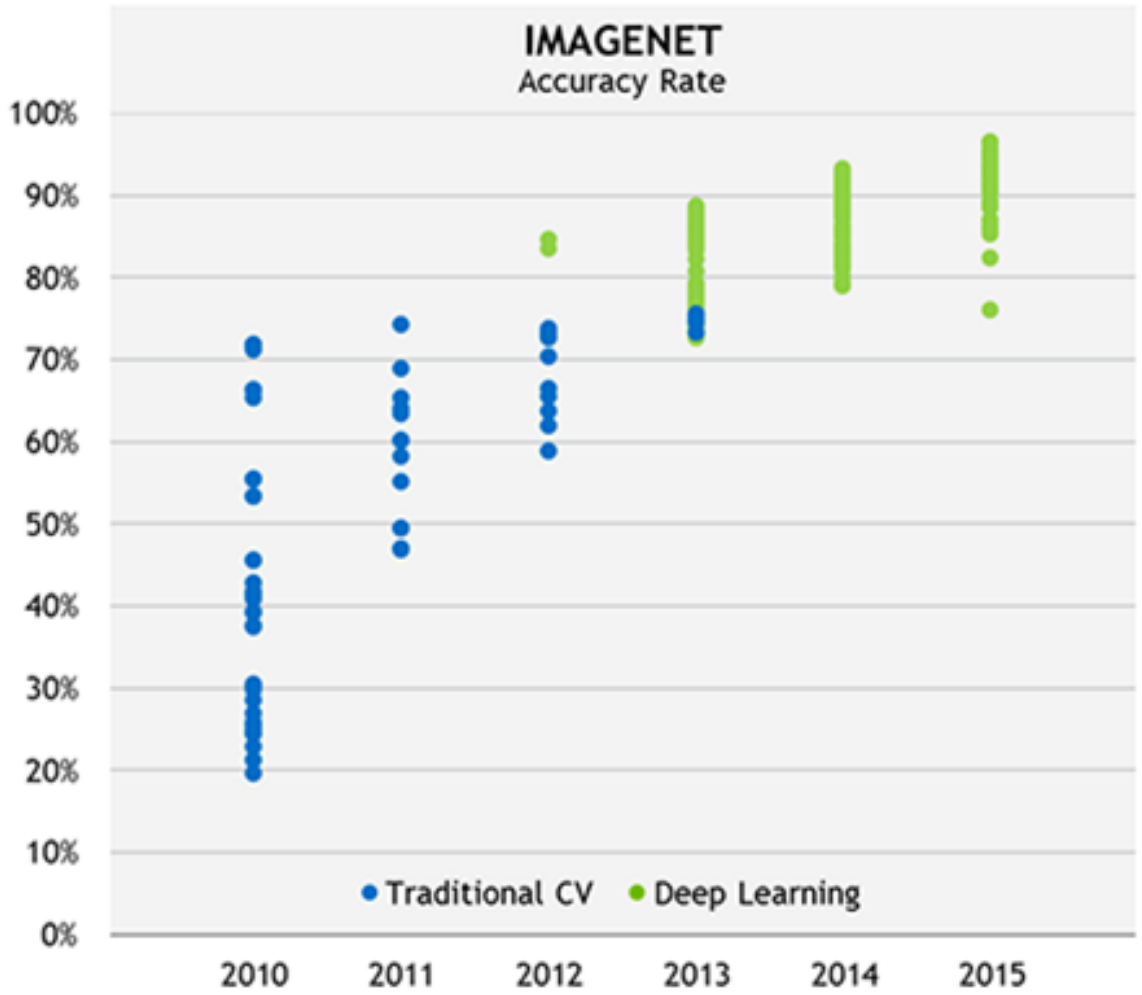
# ImageNet Challenge


- 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



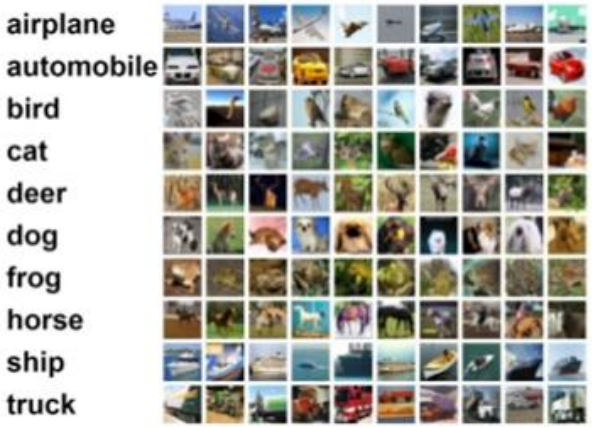



Source: https://blogs.nvidia.com/blog/2016/01/12/accelerating-ai-artificial-intelligence-gpus/

# GPU/TPU Computing

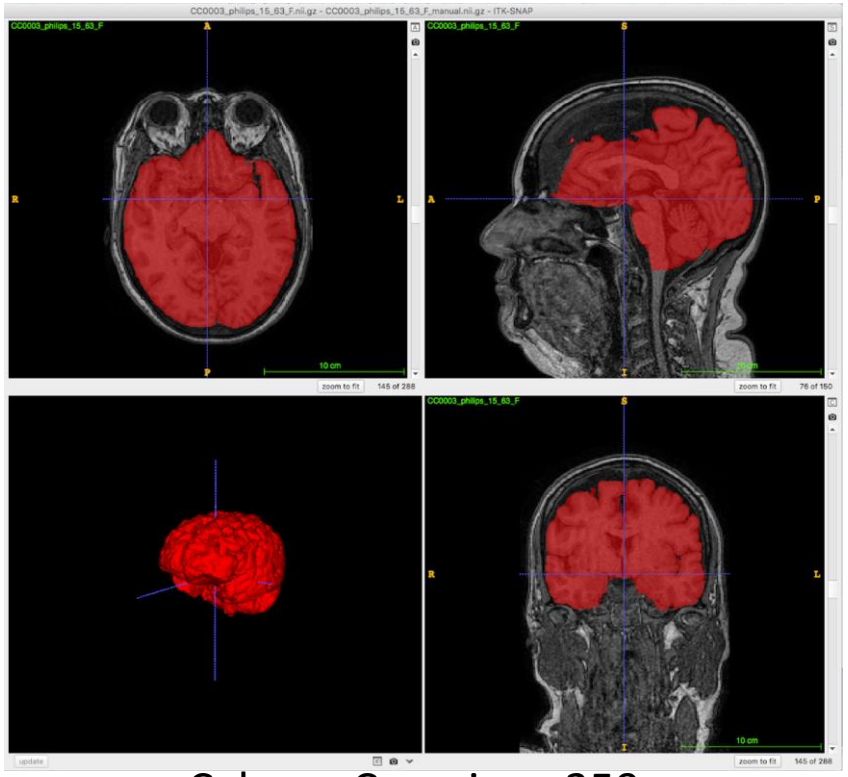
- Hardware and software improvements
- GPUs with more cores and more memory
- Optimized parallel computing platforms


# Large Datasets



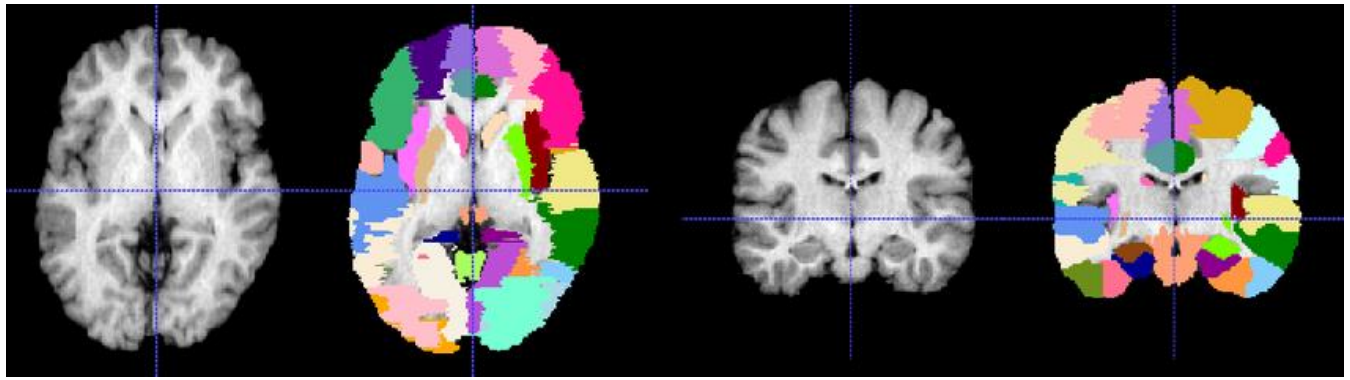

CIFAR-10

MNIST



Calgary-Campinas-359

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

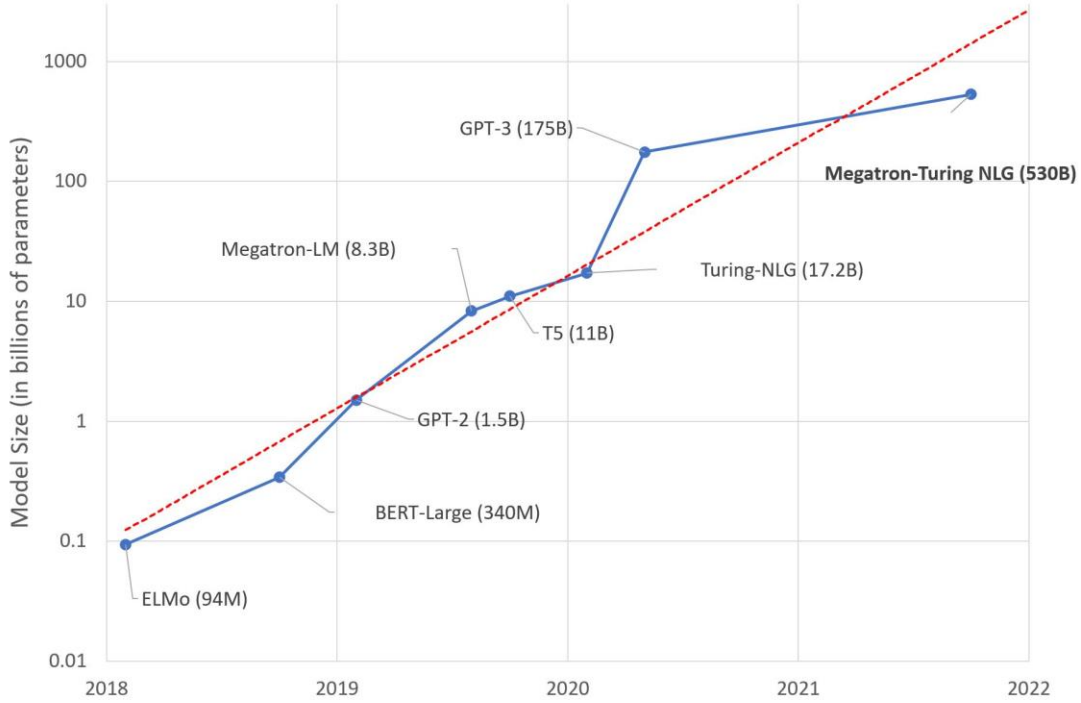


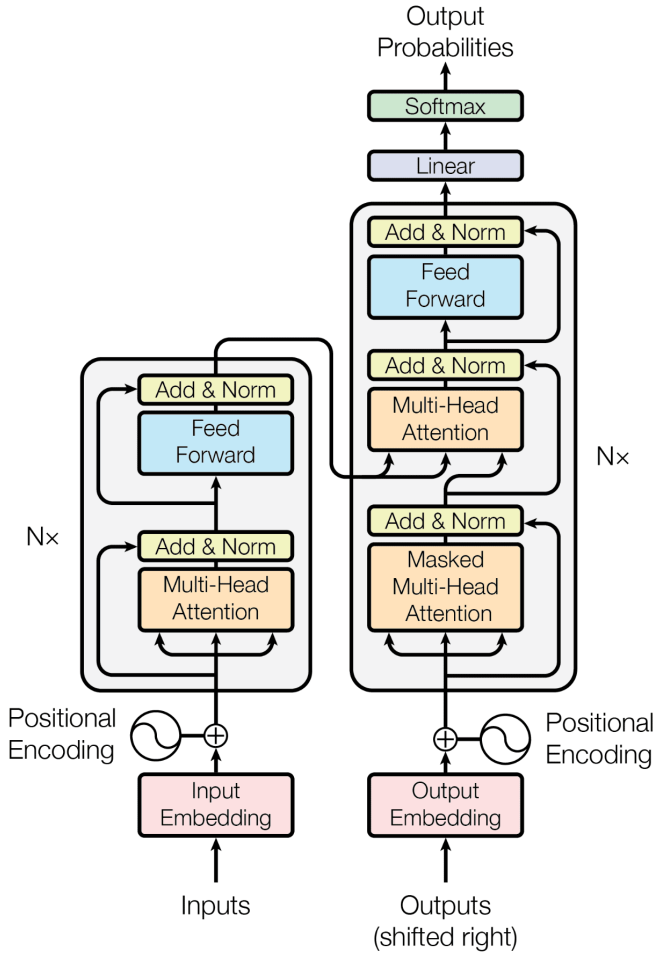
LPBA40



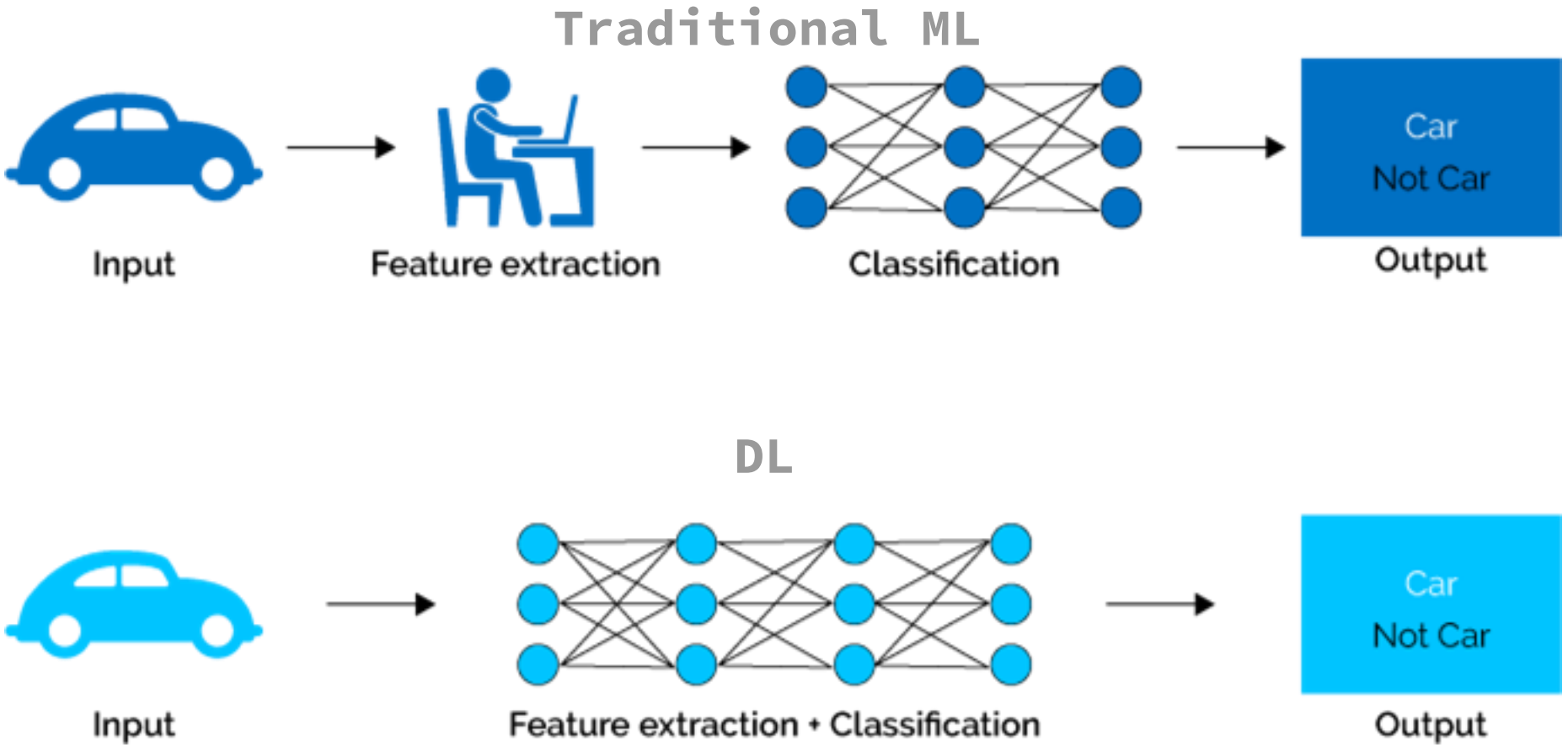
11

# Large Language Models

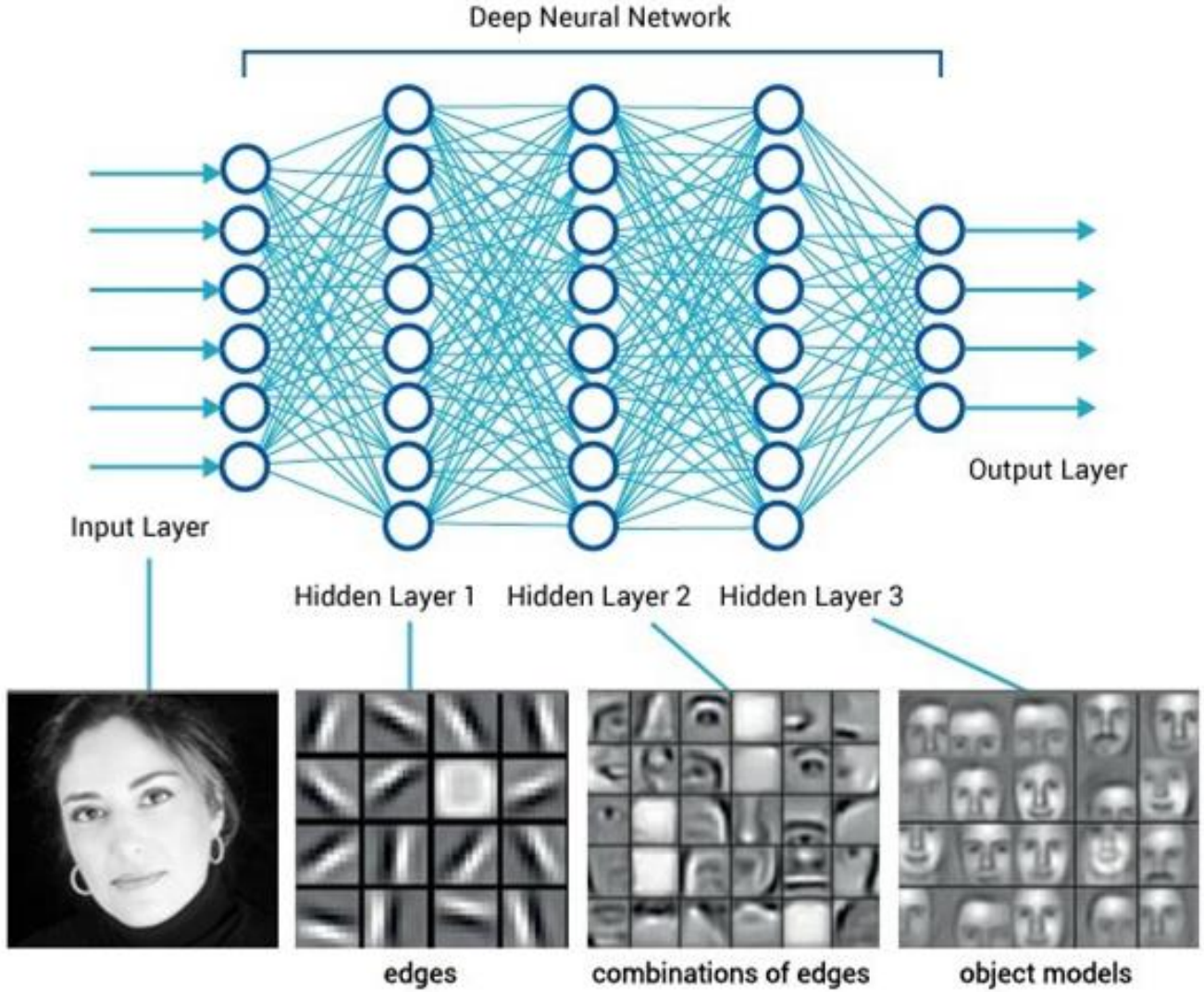



# Traditional ML versus DL



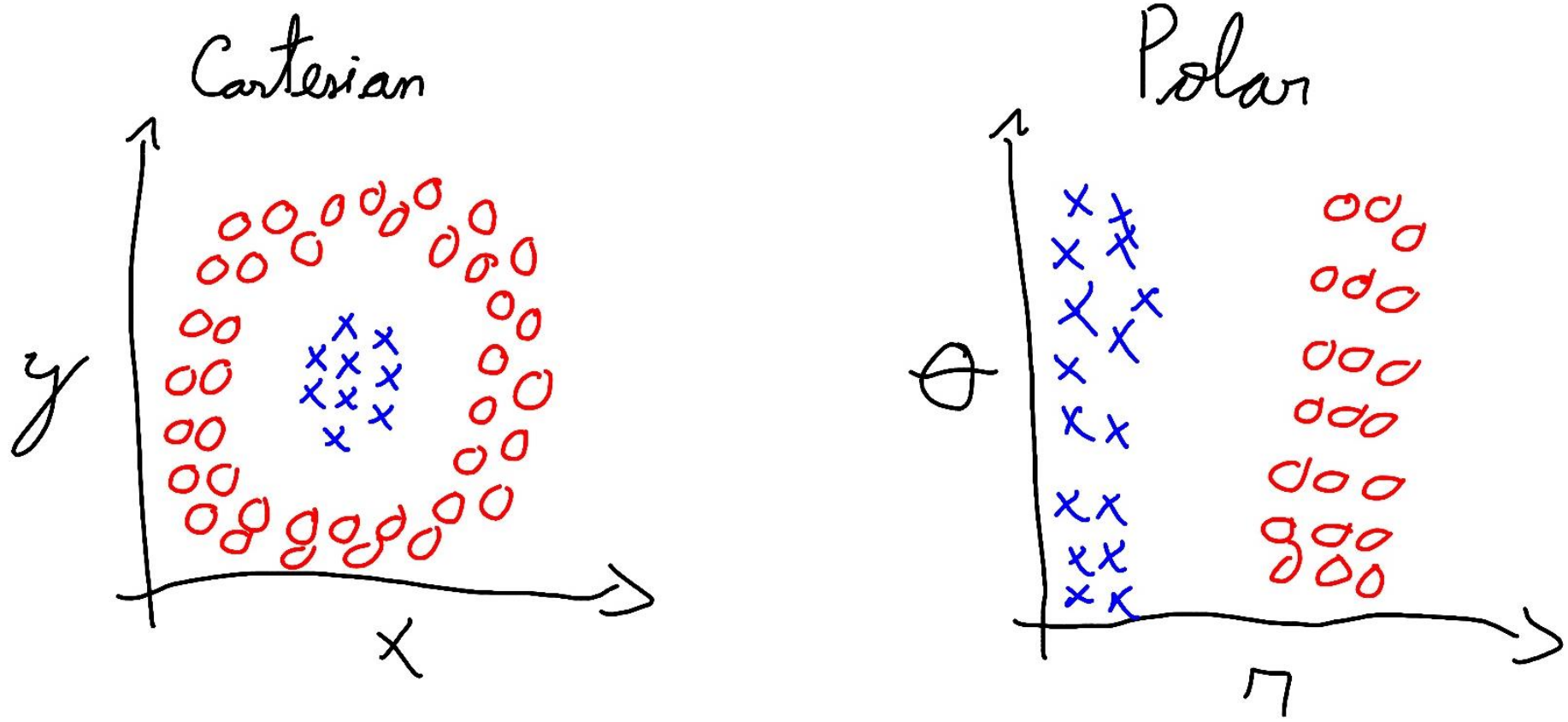
# DL Hierarchy of Concepts



# It is all about data representation….

- Roman numbers arithmetic:
  - CCCXXVII + CXXIII = ? CDL
- Arabic numbers arithmetic:
  - 327 + 123 = ? 450

# It is all about data representation….



# Scientific Community is Paying Attention…


Review Article | Published: 27 May 2015

## Deep learning

Yann LeCun ✉, Yoshua Bengio & Geoffrey Hinton

*Nature* **521**, 436–444 (28 May 2015) | Download Citation ↓


Letter | Published: 25 January 2017

## Dermatologist-level classification of skin cancer with deep neural networks

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

*Nature* **542**, 115–118 (02 February 2017) | Download Citation ↓


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)

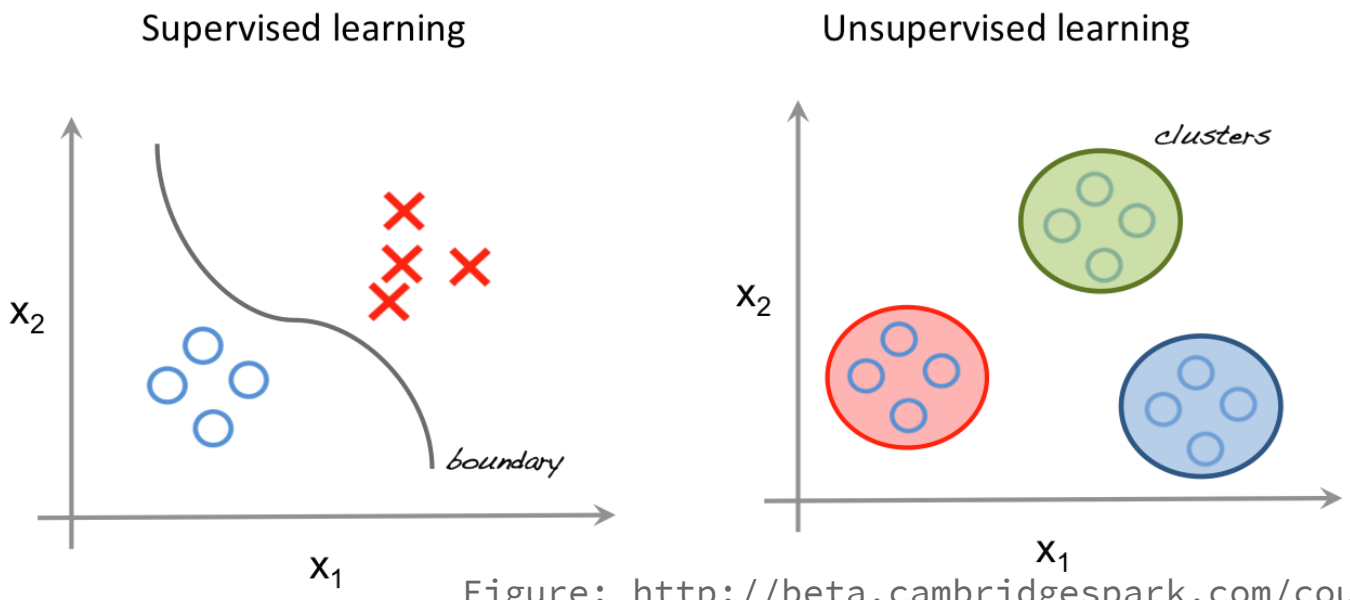
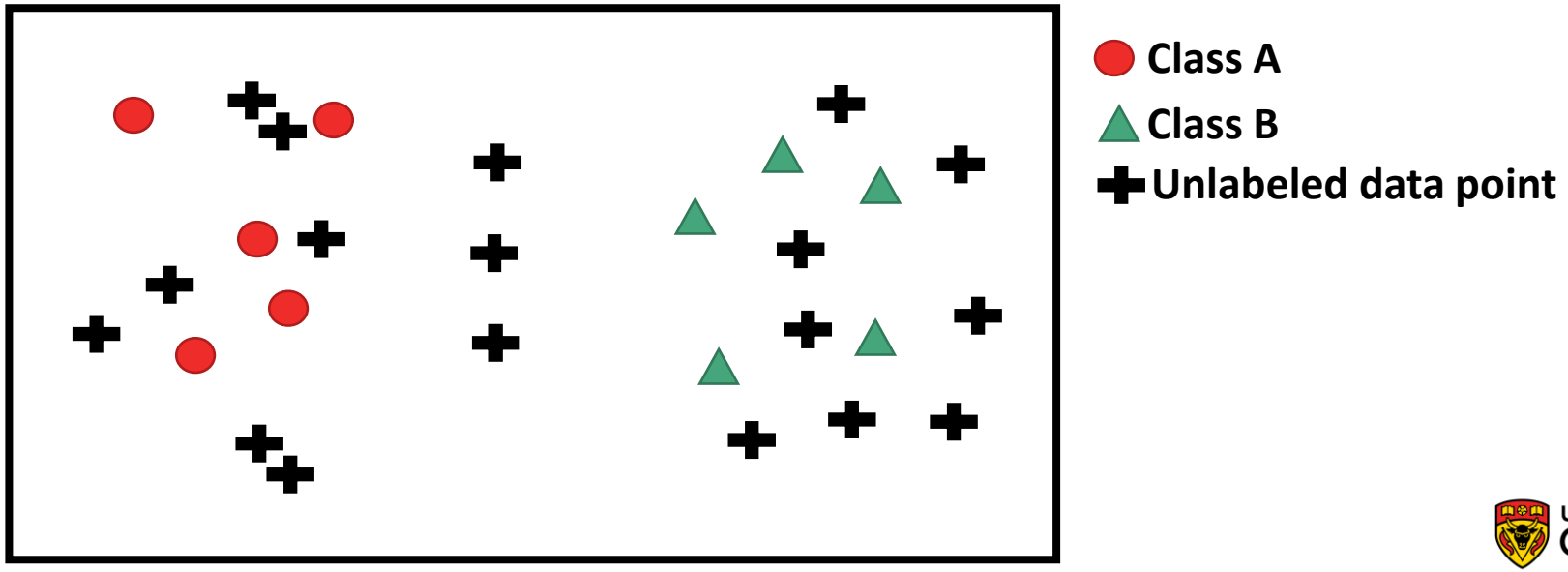



Figure: http://beta.cambridgespark.com/courses/jpm/01-module.html


18

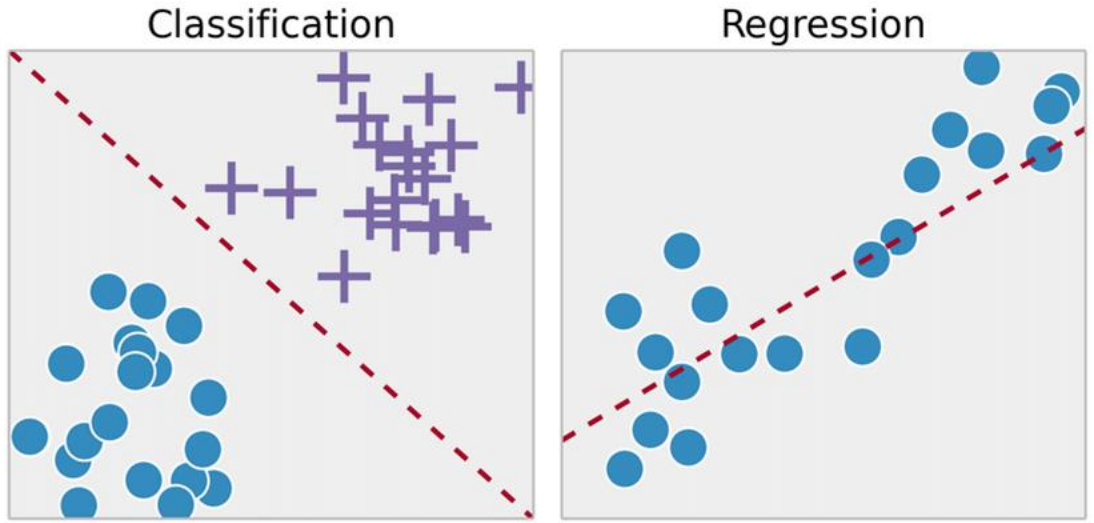
# Semi-Supervised Learning

- **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



# 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)

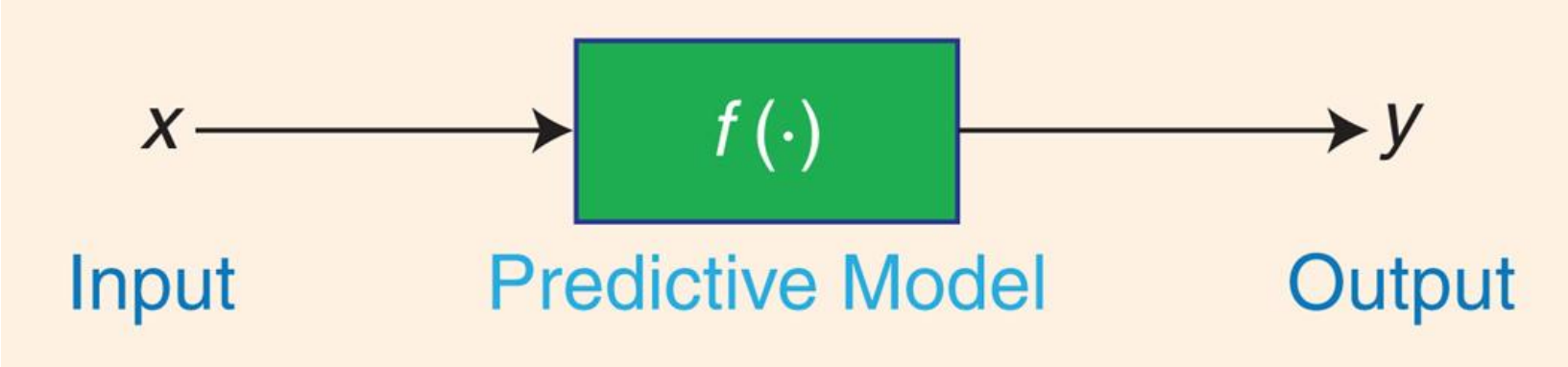




20

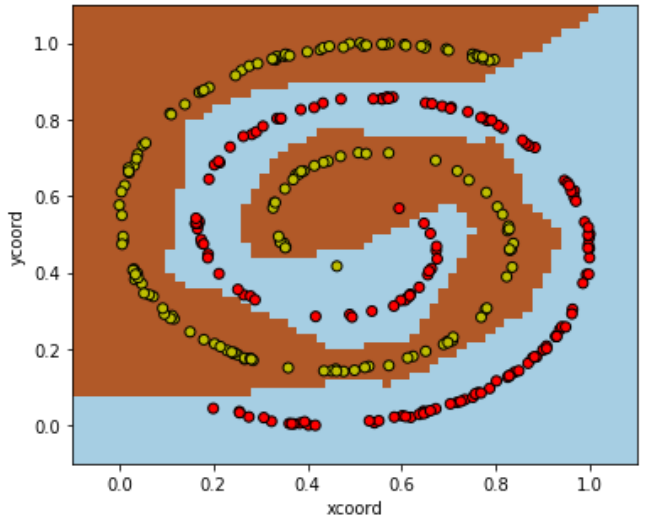
# Supervised Classification

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

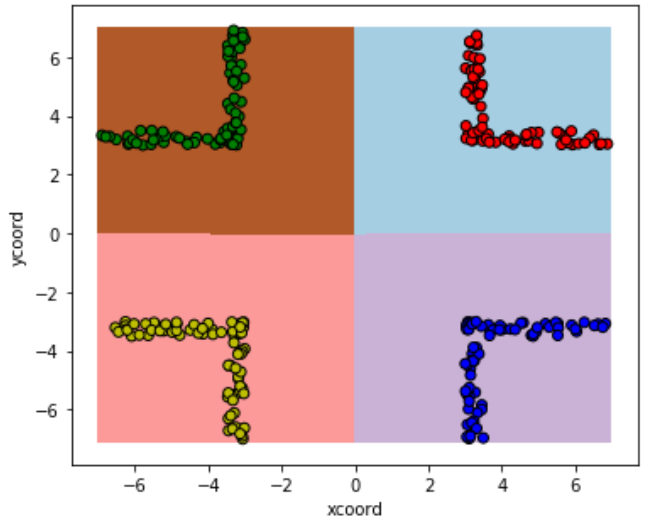


# Binary x Multi-class x Multi-label Classification

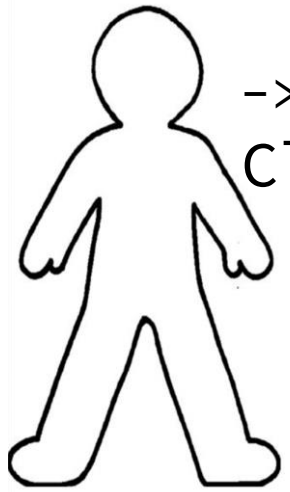
- **Binary:** 2 possible classes (labels).
- **Multi-class:** C (C>2) possible classes.
- **Multi-label:** A sample can belong to more than one class.




Binary




Multi-class



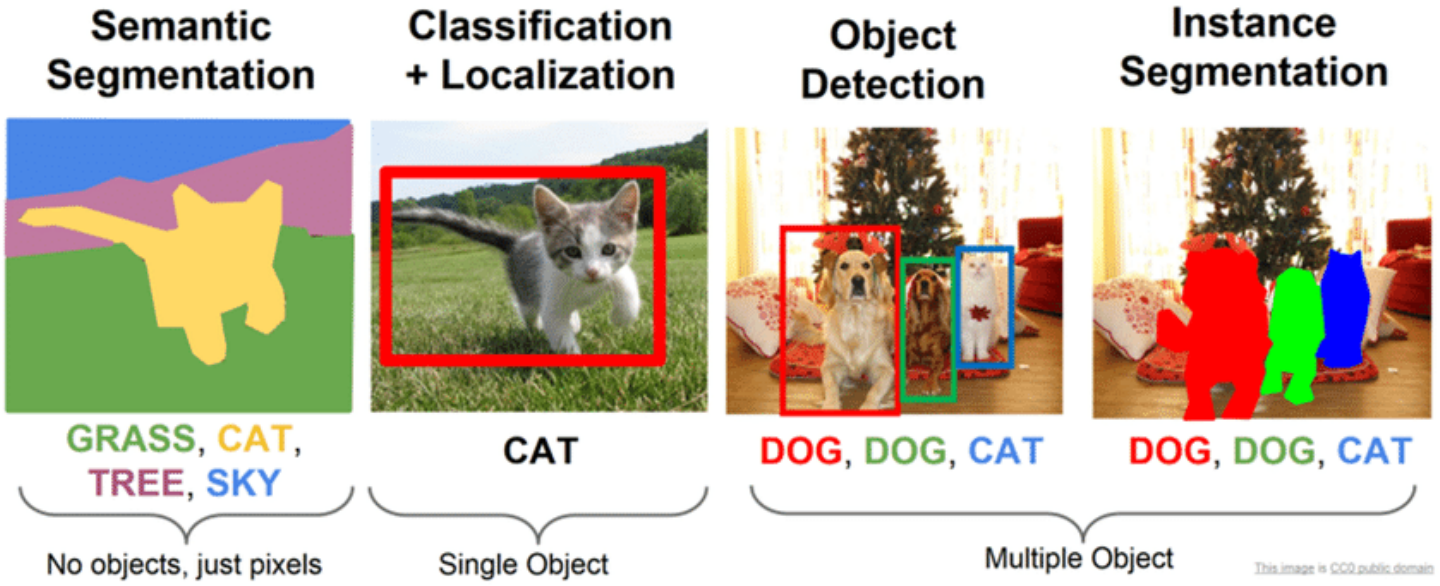
-> Class A and Class B

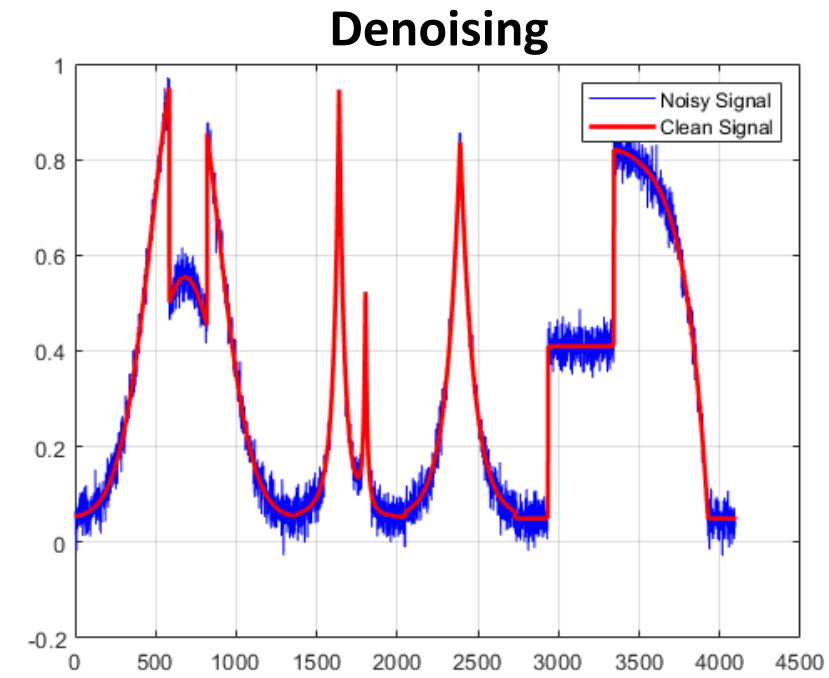
Multi-label



22

# Types of Problems



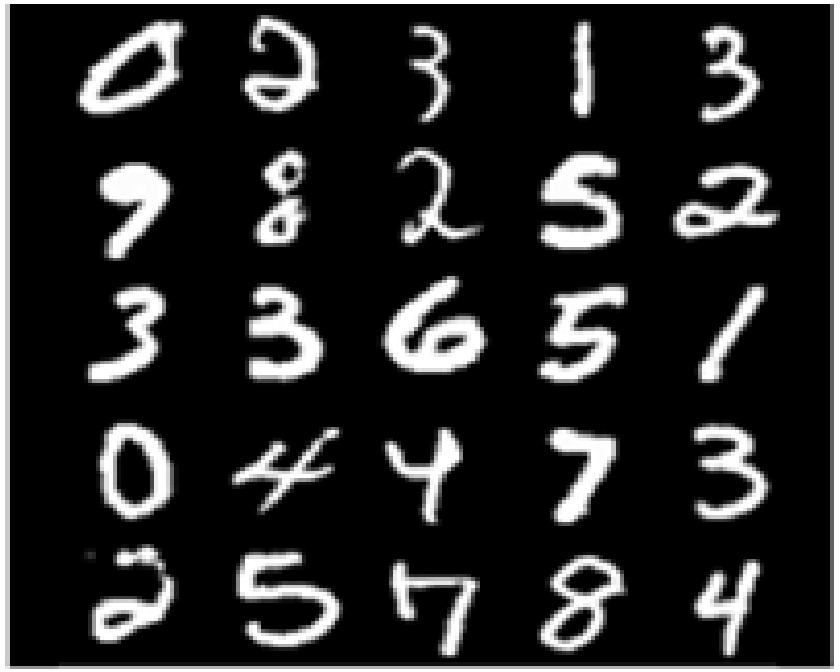





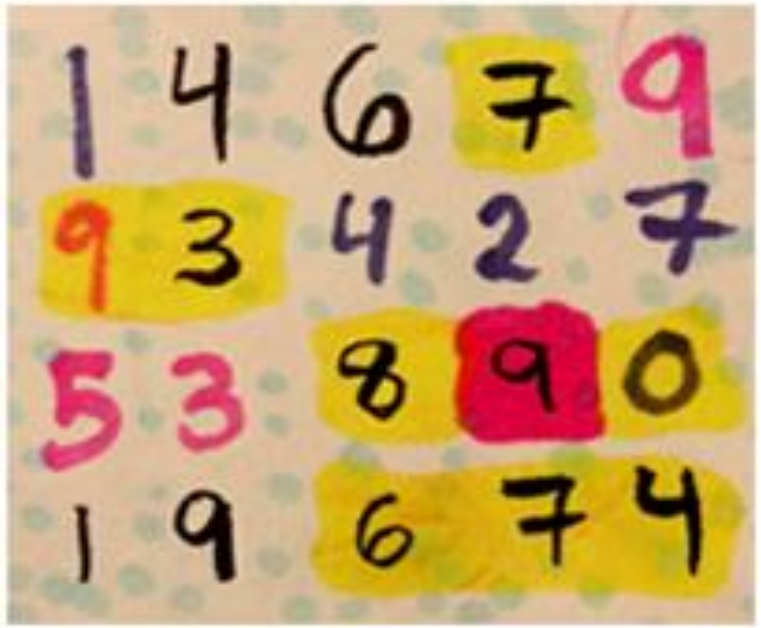

UNIVERSITY OF CALGARY

# Domain Shift

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



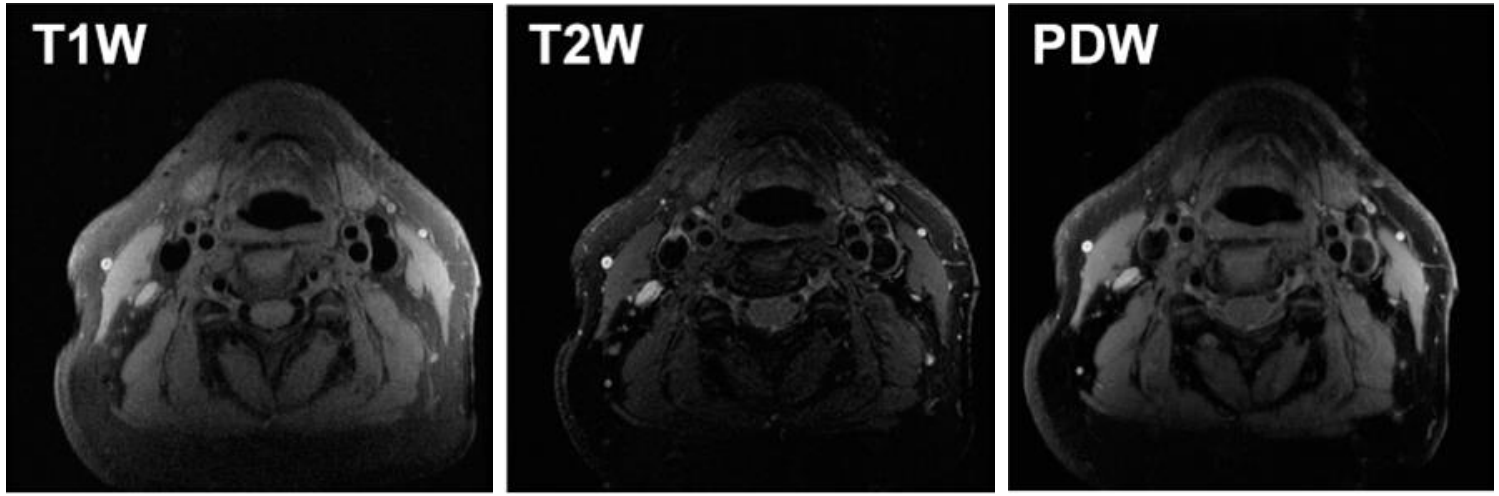
Source domain



Target domain

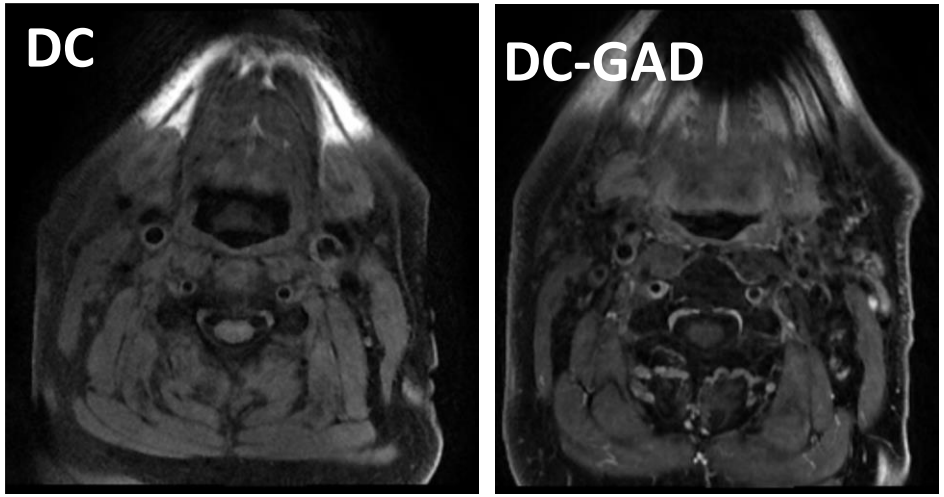
# Domain Shift

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



25

# 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!