Adversarial Networks for Data Generation and Domain Adaptation

A gentle introduction

Roberto Souza
Assistant Professor
Electrical and Software Engineering
Schulich School of Engineering

W2025

UNIVERSITY OF CALGARY

Outline

- Learning Goals
- Introduction
- Generative Adversarial Networks (GANs)
- Domain Shift and Domain Adaptation
- Domain Adversarial Neural Networks
- Summary

Learning Goals

- Introduce Generative Adversarial Networks
  - What they do
  - How they work

- Introduce domain shift and domain adaptation concepts
  - Introduce domain adversarial models for domain adaptation

Generative Adversarial Networks (GANs)

Introduction

- GANs are unsupervised deep learning methods

- GANs are considered one of the greatest deep learning breakthroughs in recent years

- There are many types of GANs
  - Wasserstein GAN
  - Cycle-GAN

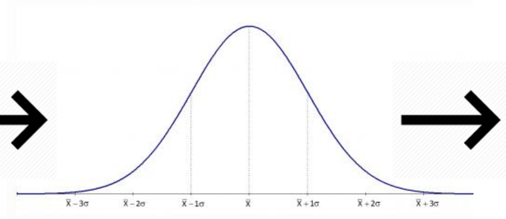
- They all operate under the same principle of having modules with adversarial (*i.e.*, competing objectives)

What are GANs?

- GANs are generative models. What is a generative model?
- We have two different models in machine learning:
  - 1) Discriminative models

  - 2) Generative models

→



→

- Dataset
- Learning distribution
- New data

Machine Learning Models

- Generative Models
  - Generate realistic representation for each class.

Random Numbers → Generative Model →

$(-5,\ 3,\ \begin{bmatrix}-5\\3\\1\end{bmatrix})$

Noise (ε)

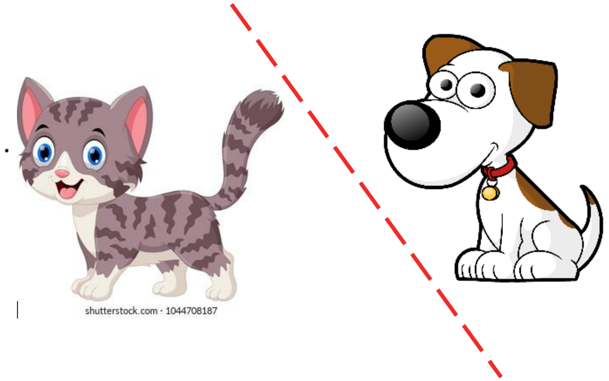
Y, ε → X (features)

$$P\,(X\,|\,Y)$$

or

$$P\,(X)$$

- Discriminative Models
  - Used for classification problem



→ Discriminative Model → Class

X (features) → Y

$$P\,(Y\,|\,X)$$

Generative Adversarial Networks

To produce Realistic Presentation of different classes

To distinguish real images from fake ones (produced by generator)

$\begin{bmatrix}-5\\3\\1\end{bmatrix}$ → Generative Model →

→ Discriminative Model → Fake/ Real

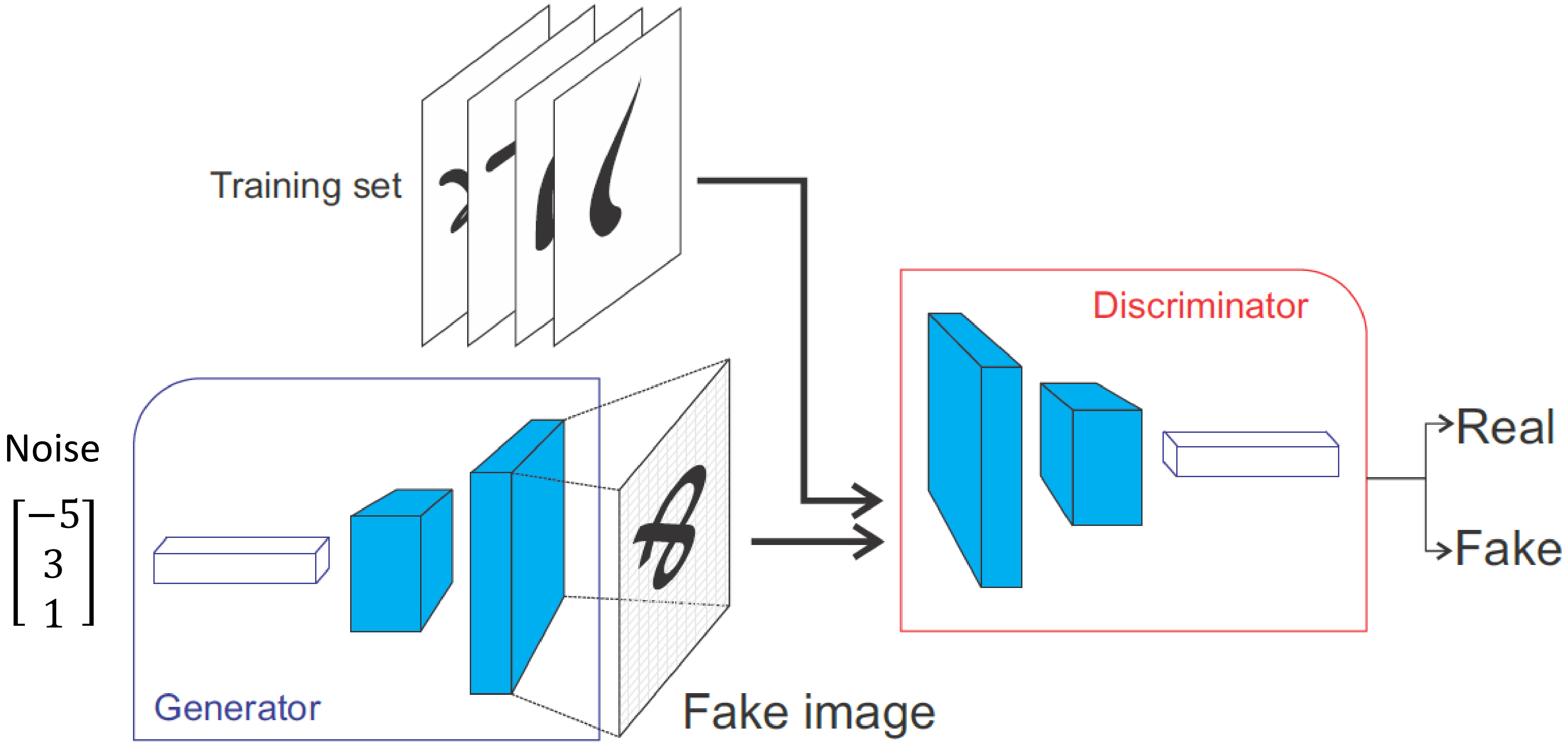
There is a competition here !

Generator tries to make fakes that look real and fool the discriminator

Discriminator learns how to distinguish reals from fakes

GANs are generative models where the data distribution is learned implicitly!

GAN



Training set
Discriminator
Noise
$\begin{bmatrix} -5 \\ 3 \\ 1 \end{bmatrix}$
Real
Fake
Generator
Fake image

GANs Problems

- **Non-convergence**: the model parameters oscillate and the model does not converge
- **Mode collapse**: the generator collapses and produces a limited number of different samples
- **Diminished gradient**: the discriminator is too good that the generator gradient vanishes and learns nothing,
- **Highly sensitive** to the hyperparameter selections.

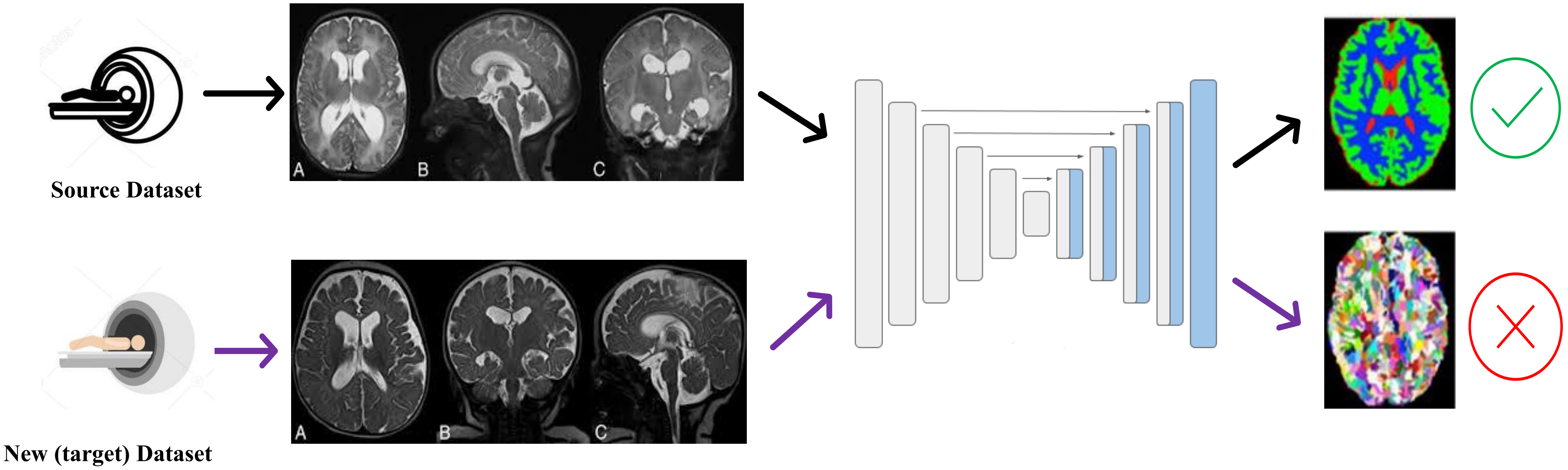
Summary

- GANs are unsupervised techniques
- They can be used to generate synthetic data that can potentially be used to train other deep learning models
- There are different GAN types, but they are all based on the principle of having two competing objectives
- GANs often face instabilities during training

UNIVERSITY OF CALGARY

Domain Shift and Domain Adaptation

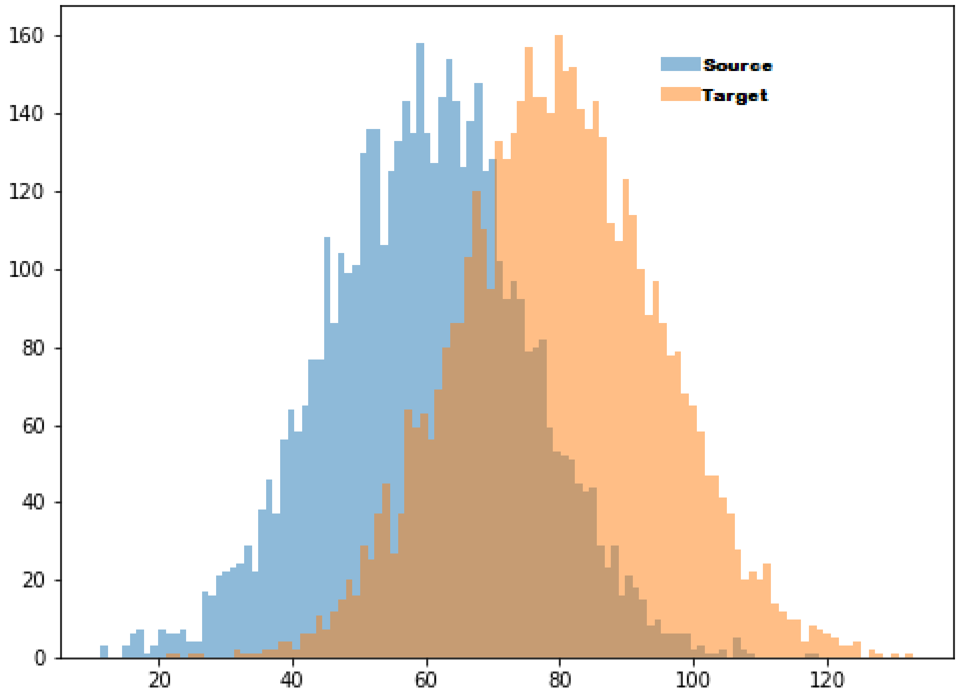
Motivation



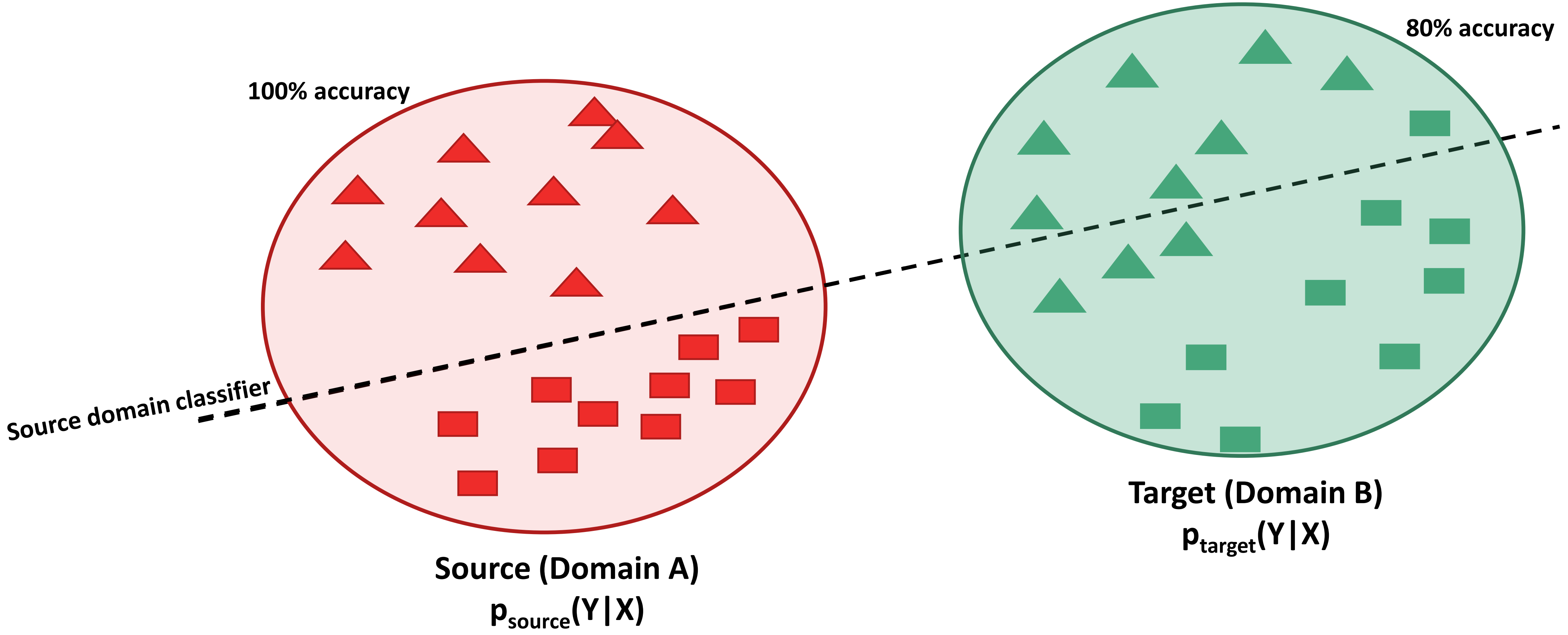
Domain Shift

- **Domain shift**: refers to the change of data distribution between one dataset (source/reference domain) and another dataset (target domain).

$$p_{source}(Y|X) \neq p_{target}(Y|X)$$



Domain Shift Problem

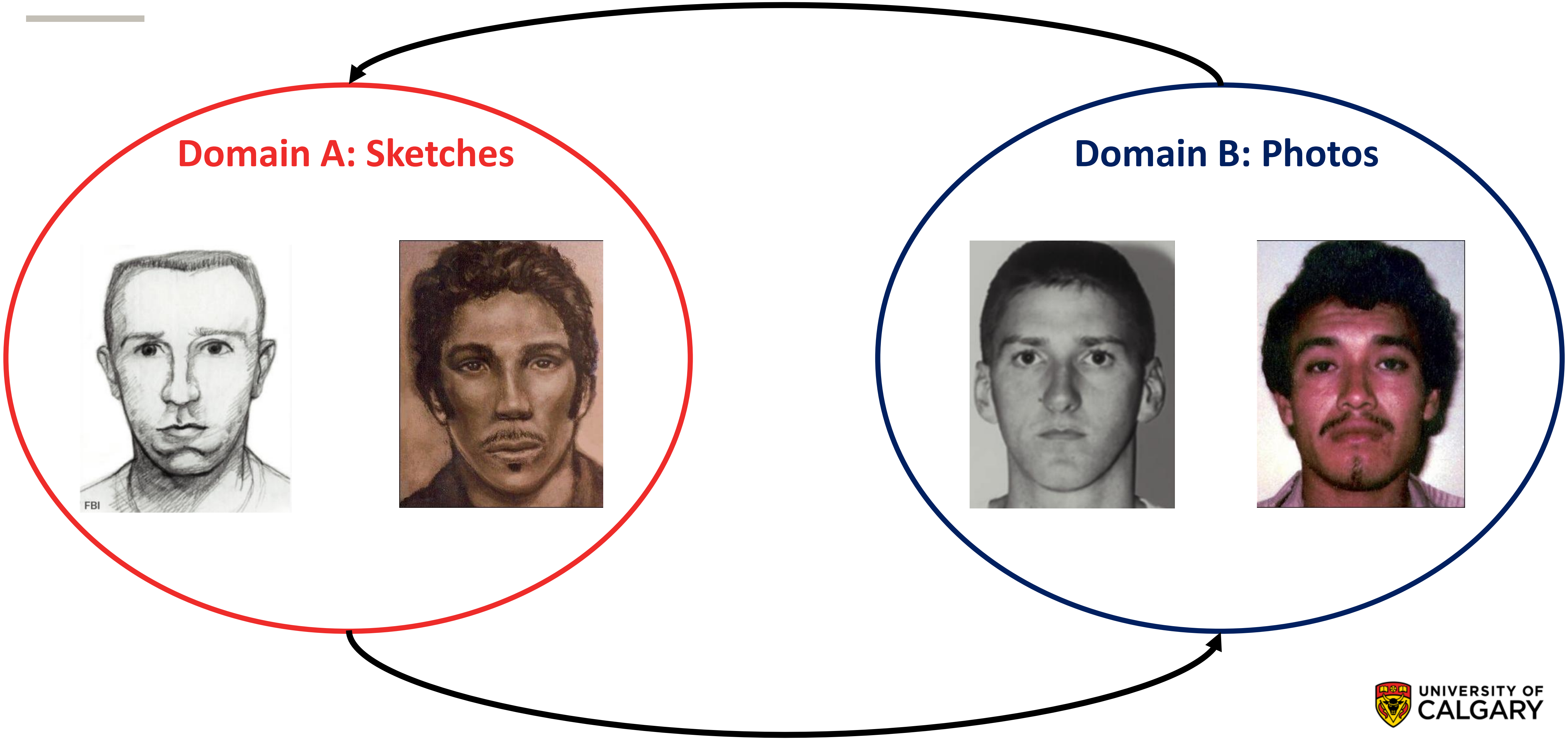


Different Types of Images

Domain A

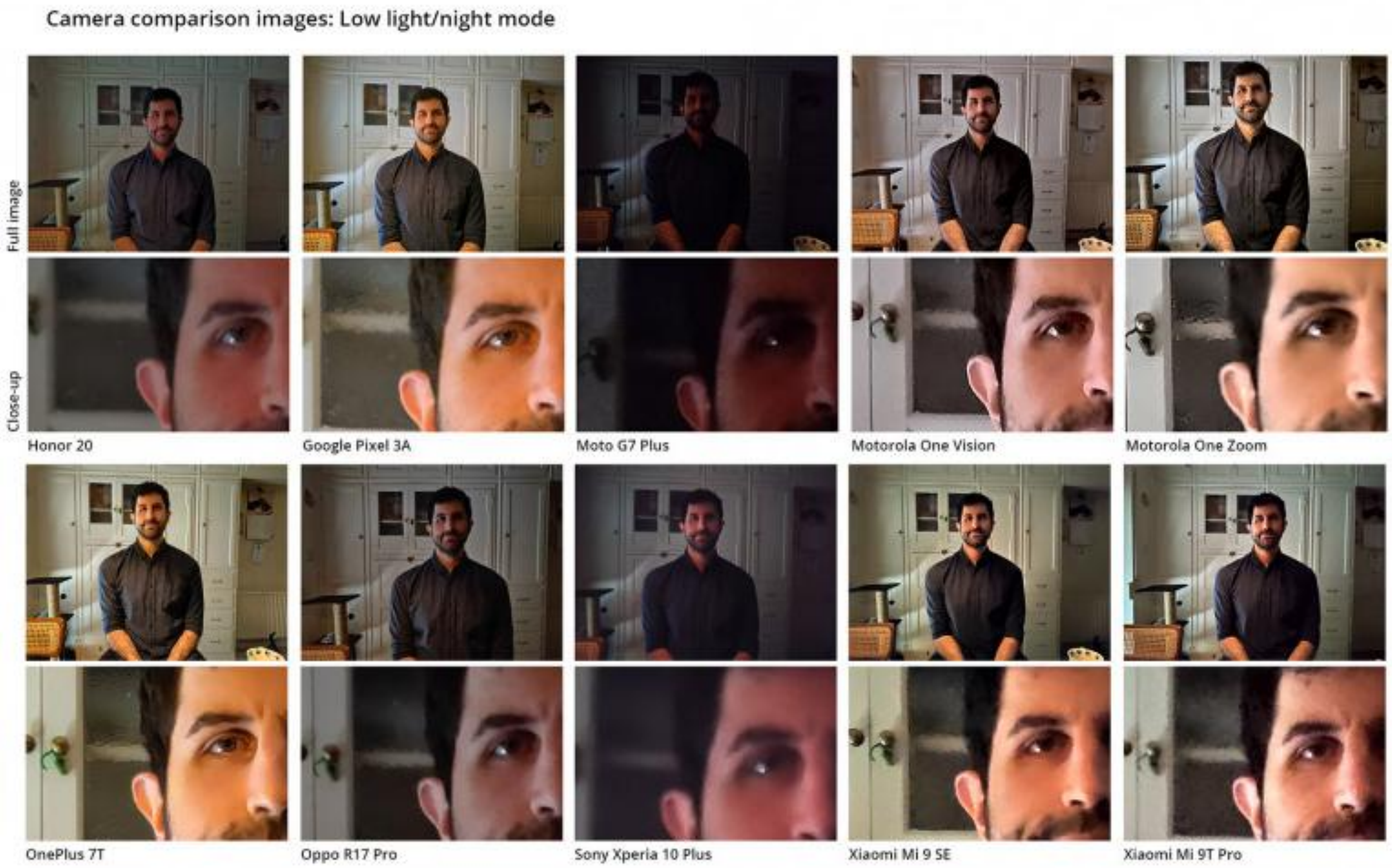
Domain B

Different Types of Images: Sketches and Photos



UNIVERSITY OF CALGARY

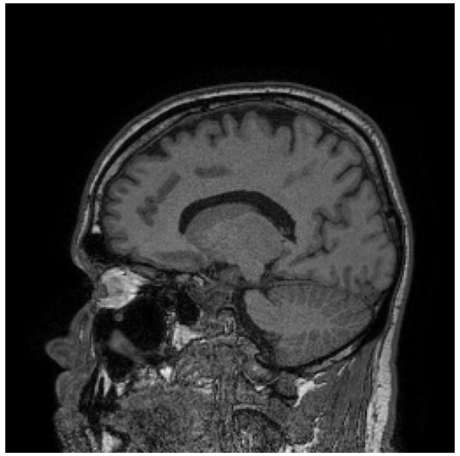
Technology Differences and Evolution



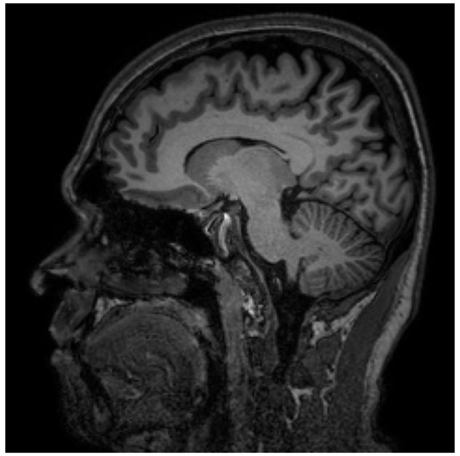
UNIVERSITY OF CALGARY

Hardware and Software Differences

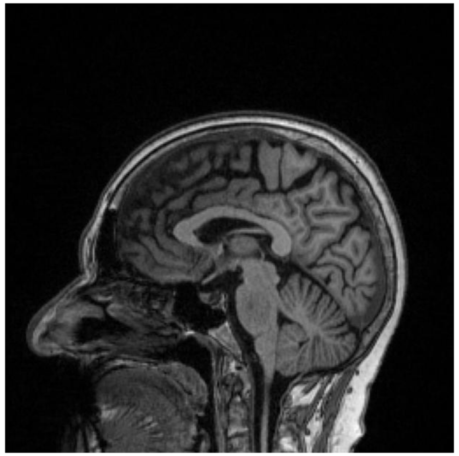
philips_15



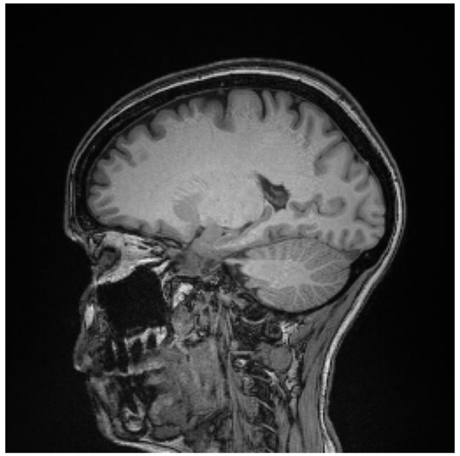
philips_3



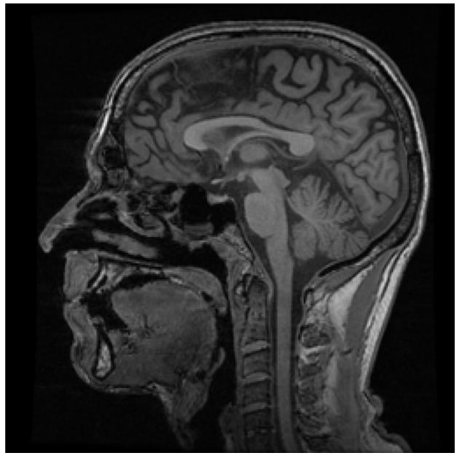
siemens_15



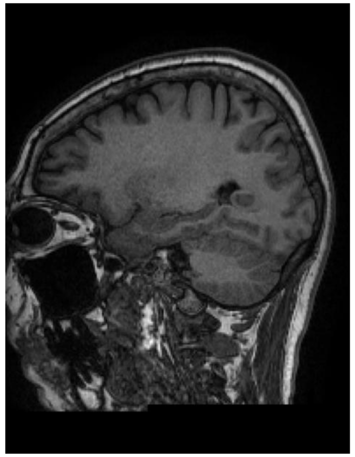
siemens_3

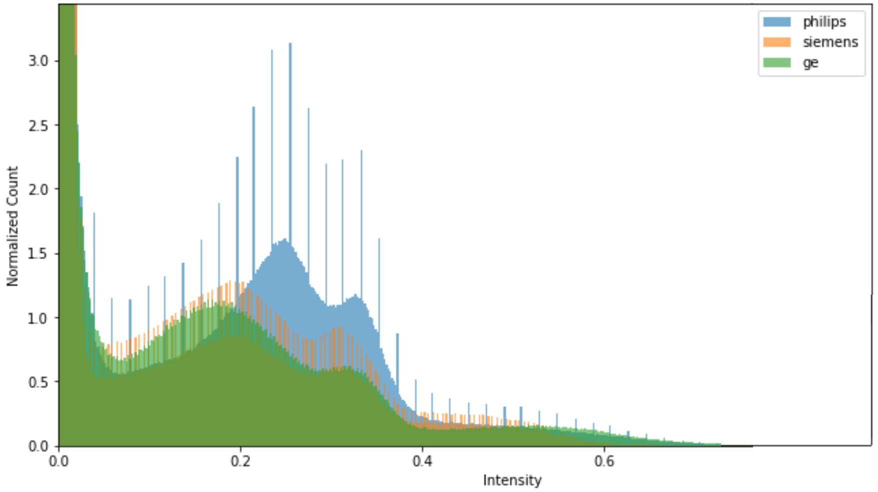


ge_3



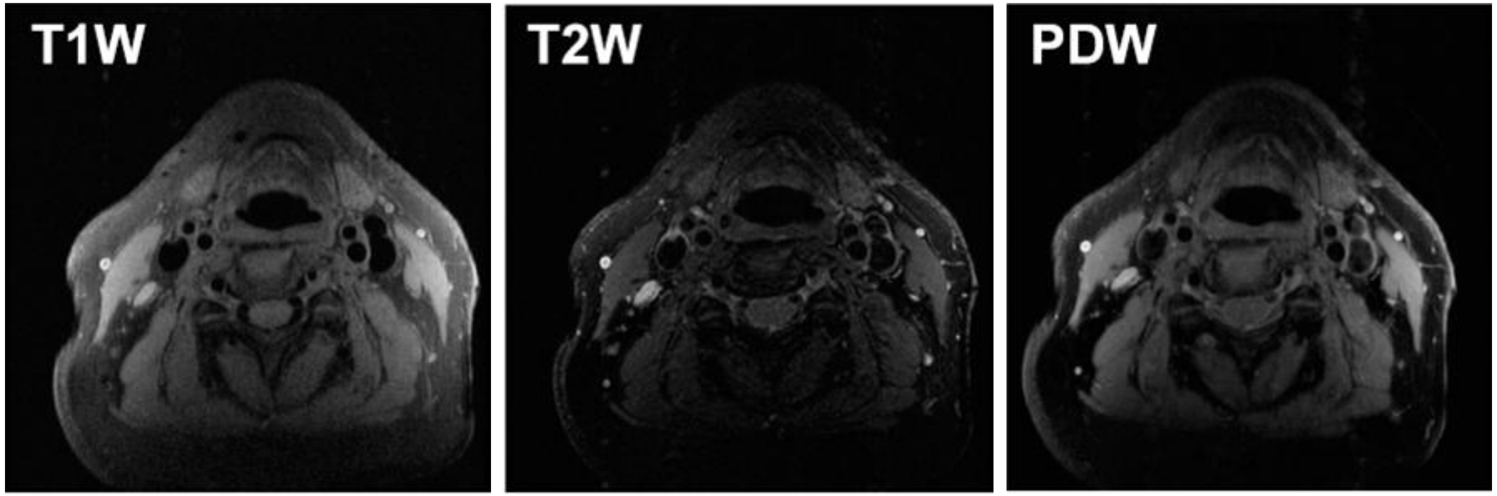
ge_15





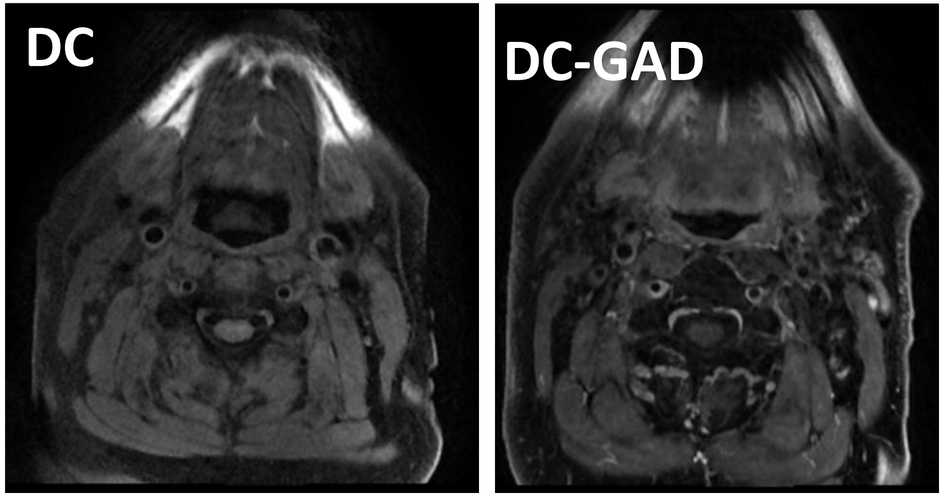
Hardware and Software Differences

AIM-HIGH Study



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

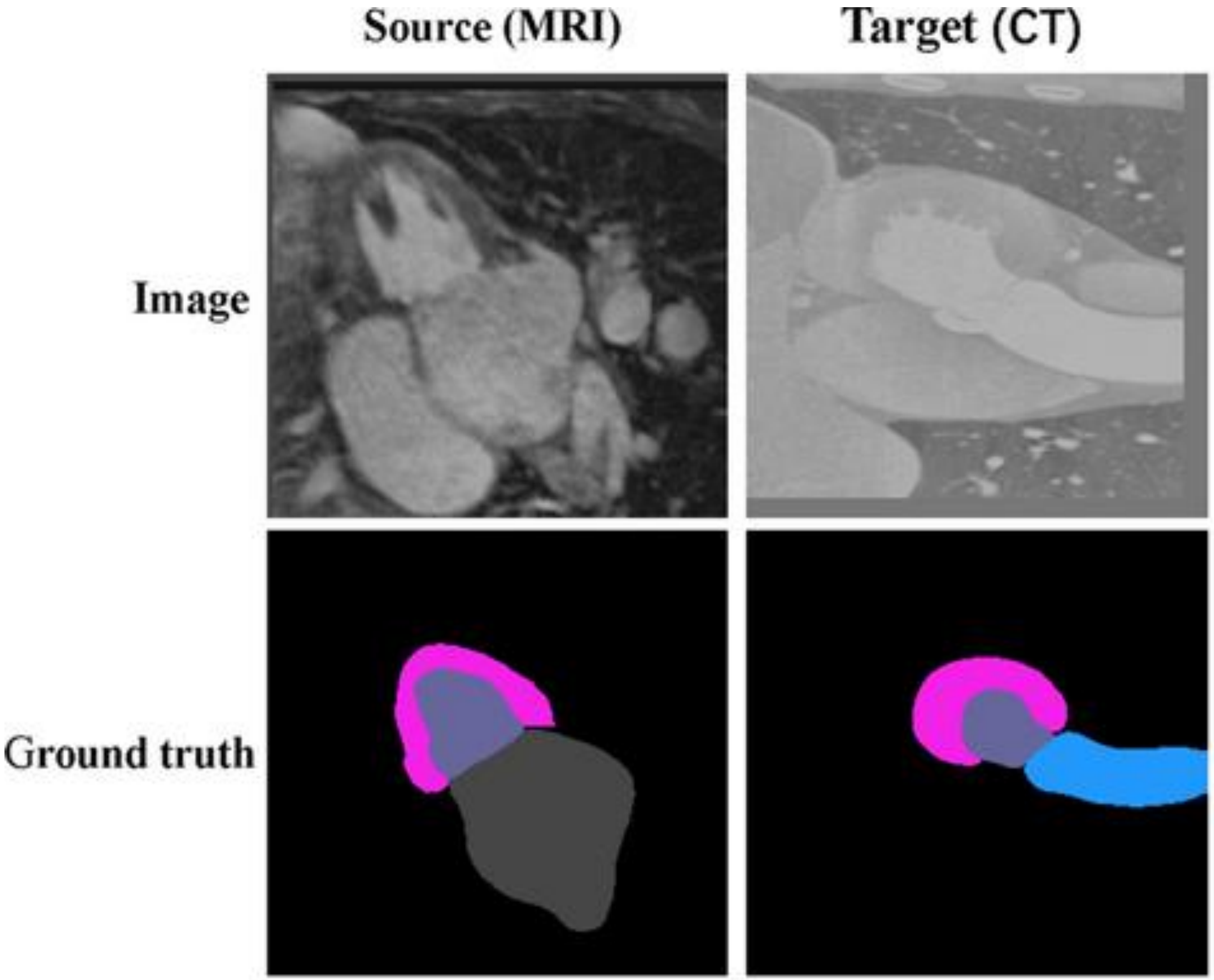
CARDIS Study



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

UNIVERSITY OF CALGARY

Different Technologies



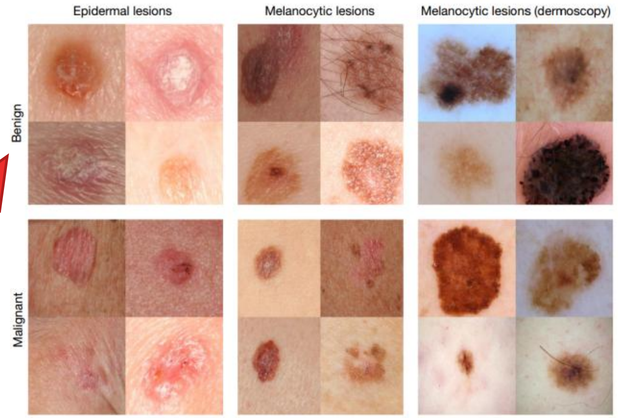
Degree of Domain Shift

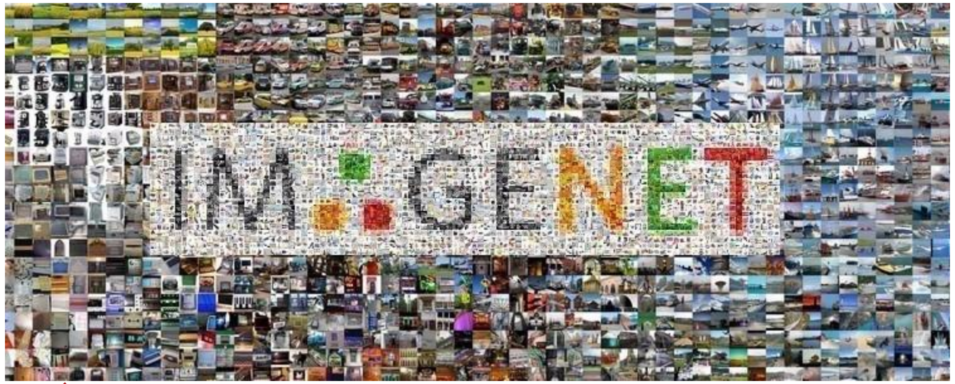
- **Degree of domain shift** is a measure of how much the distributions of the source and target domains are different

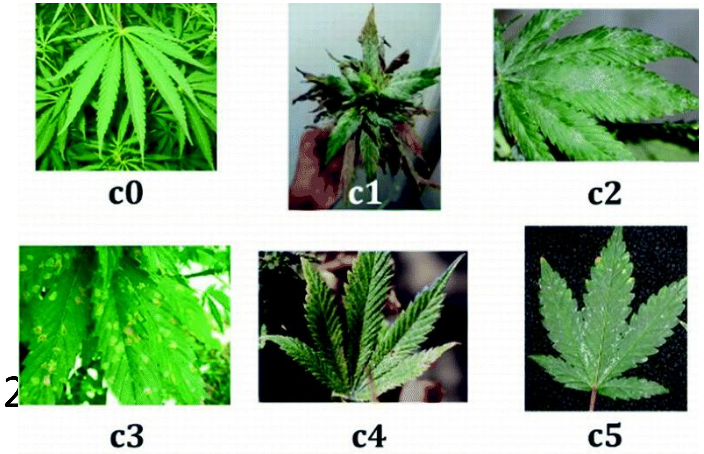
- Previous studies have revealed that the test error generally increases in proportion to the degree of domain shift.

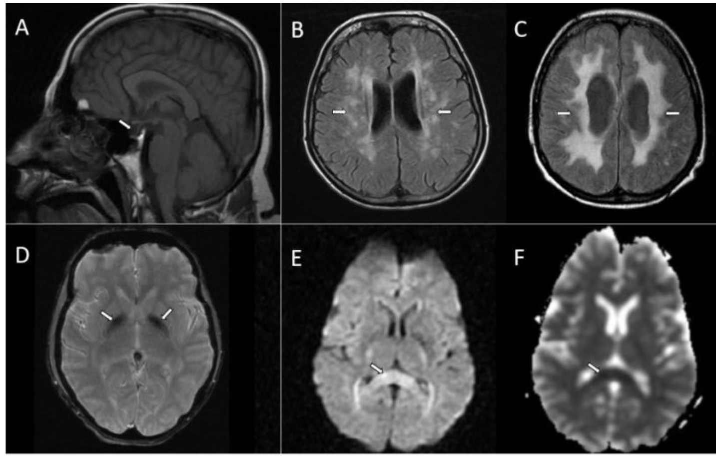
Degree of Domain Shift

Small or large shift?



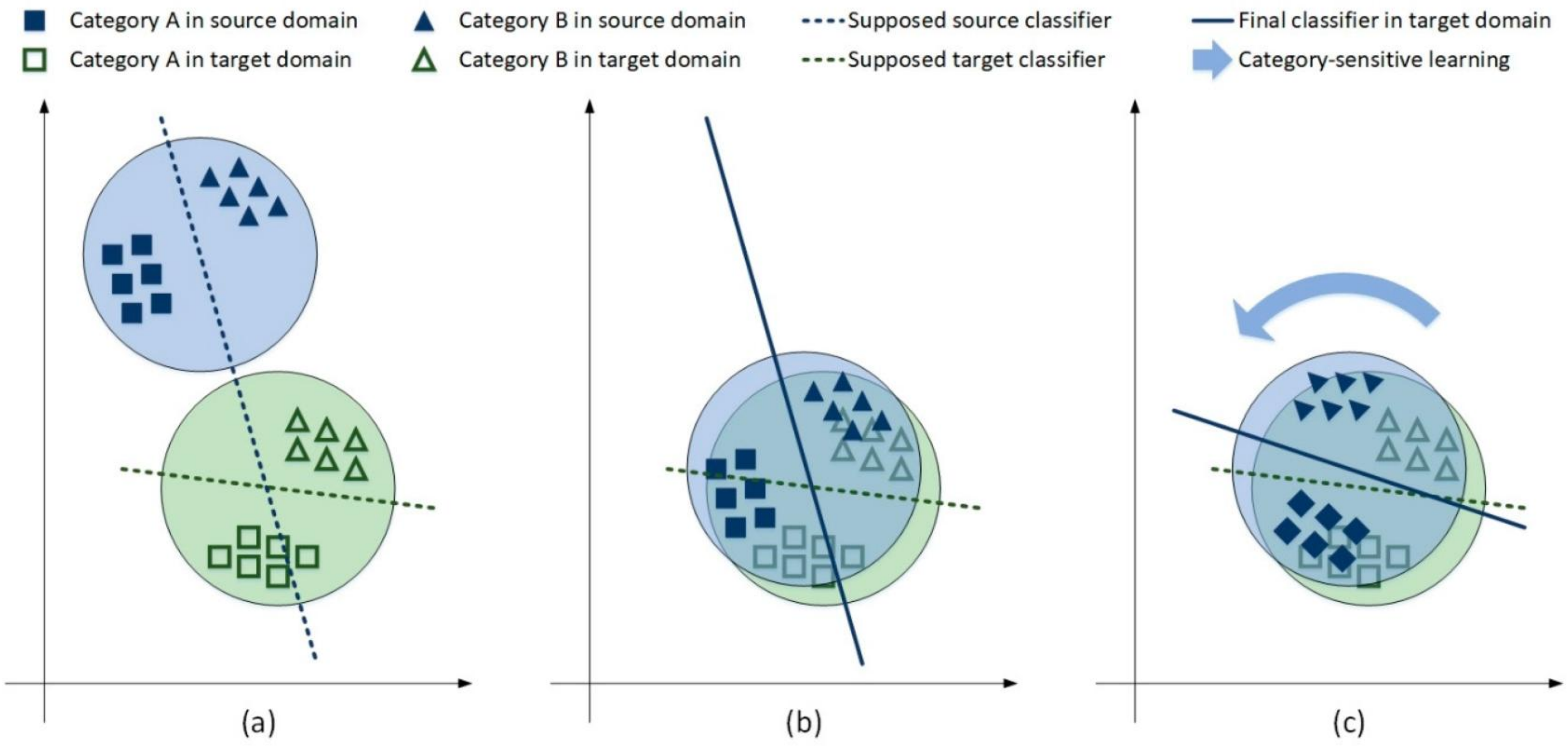




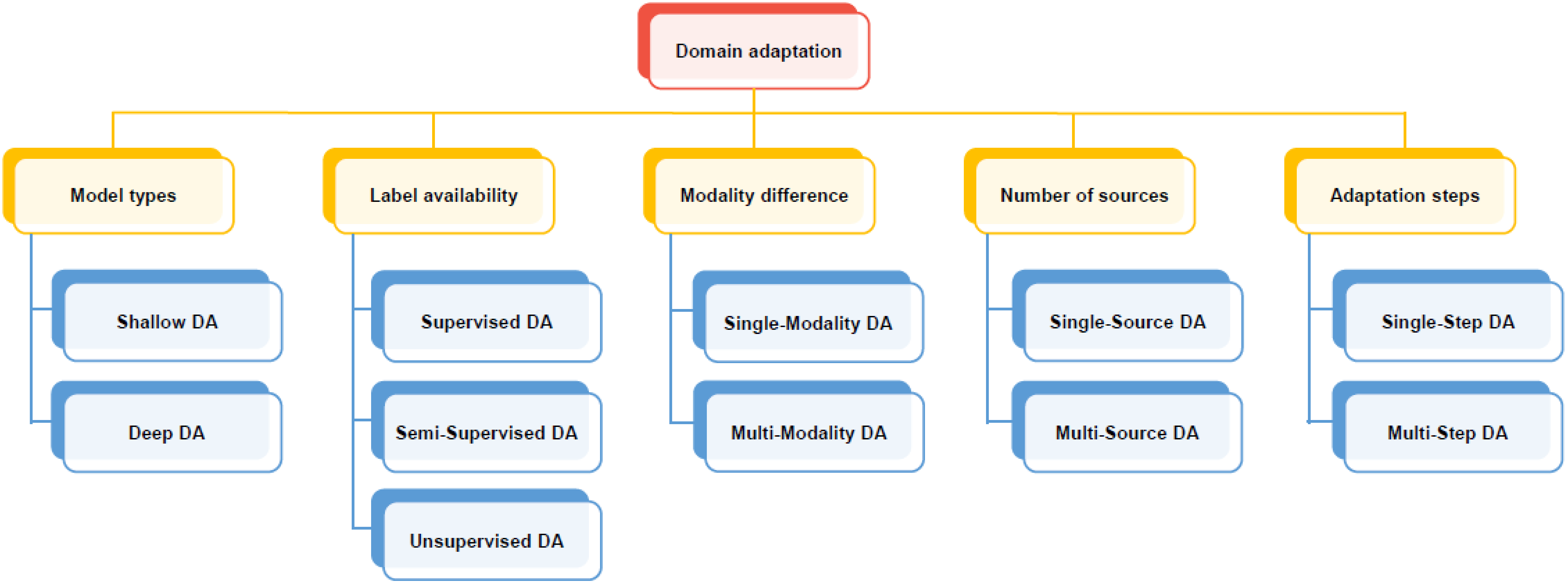


Domain Adaptation

- **Domain adaptation**: domain adaptation refers to adapting a model trained in one or more source domains to a different one or more target domains.



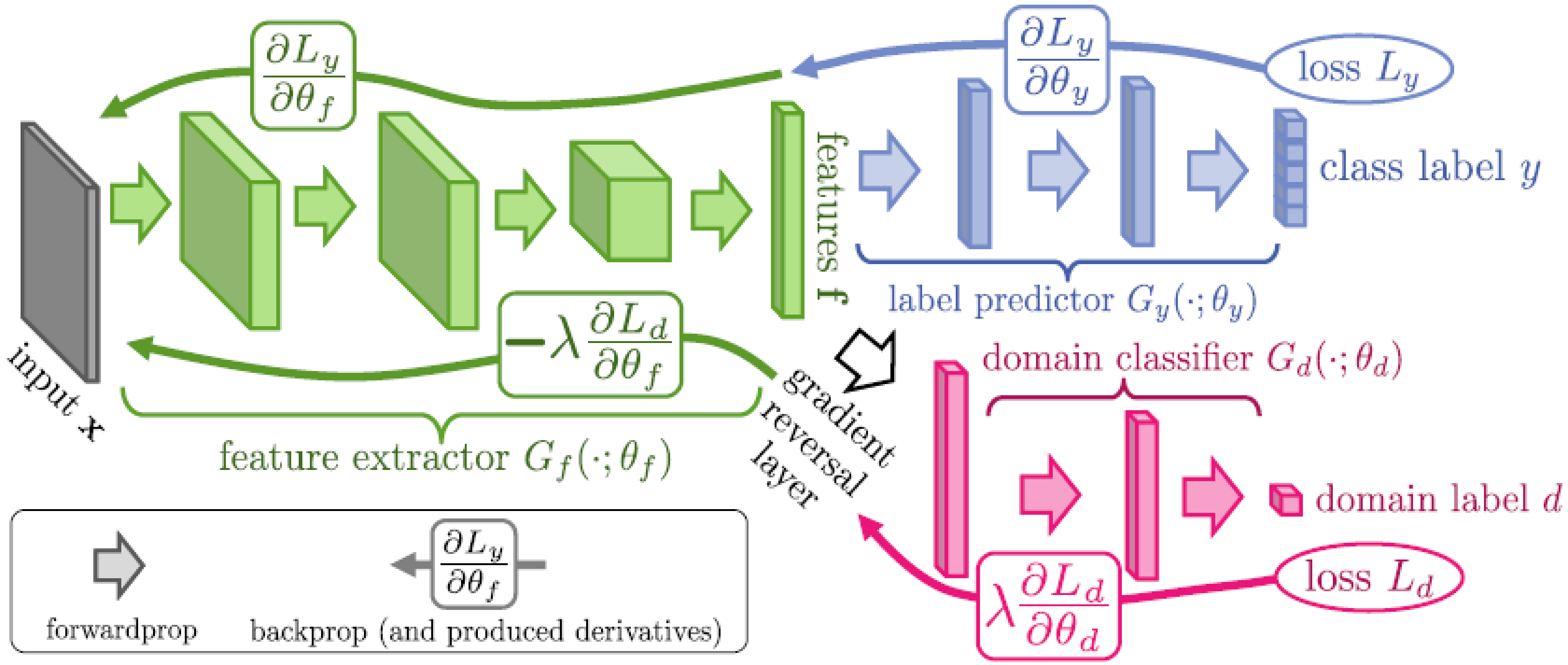
Domain Adaptation Categories



Supervised Domain Adaptation

- Essentially transfer learning
  - Fine-tune all layers
  - Fine-tune initial layers
  - Fine-tune final layers

Domain-Adversarial Training of Neural Networks (Unsupervised)



*Ganin et al., JMLR, 2016

$$E(\theta_f, \theta_y, \theta_d) = \frac{1}{n}\sum_{i=1}^{n} \mathcal{L}_y^i(\theta_f, \theta_y) - \lambda\left(\frac{1}{n}\sum_{i=1}^{n} \mathcal{L}_d^i(\theta_f, \theta_d) + \frac{1}{n'}\sum_{i=n+1}^{N} \mathcal{L}_d^i(\theta_f, \theta_d)\right)$$

Summary

- Domain shift is a problem in machine learning that can make model performance decrease when there is a distribution shift in the test data

- Domain adaptation techniques can be used to make models more robust to data domain shifts

Thank you!