Transfer Learning

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Sumário

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Introduction: Overview

- Transfer Learning was initially proposed in 1995 as a way to repurpose previously learned knowledge through machine learning algorithms;
- Through Transfer Learning , the model can be pre-trained on data from a specific domain, and, then, adapted to meet the needs of the given task, or extracts information from one domain (source domain) and passing it on to another (called target domain);
- So, Transfer Learning allows learning from a limited number of data samples by transferring extracted knowledge from one or more domains to a relevant target domain. In other words, it solves the training data problem in the target domain with more knowledge gained from the source domain.

Introduction: Overview

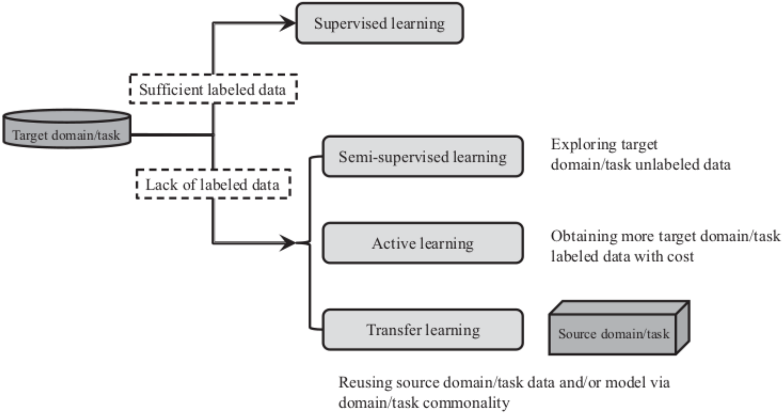

Figura: Source: [Yang 2020]

Introduction: Notation and Definitions

A **domain** $\mathbb{D}$ consists of two components: a **feature space** $\mathcal{X}$ and a **marginal probability distribution** $\mathbb{P}^X$, where $\mathbf{x} \in \mathcal{X}$ denotes each input instance.

Given a domain $\mathbb{D} = \{\mathcal{X}, \mathbb{P}^X\}$, a **task** $\mathbb{T}$ consists of two components: a **label space** $\mathcal{Y}$ and a **function** $f(\cdot)$. So we can write $\mathbb{T} = \{\mathcal{Y}, f(\cdot)\}$.

The function $f(\cdot)$ is a predictive function that can be used to make predictions on unsee instances $\{\mathbf{x}^*\}s$. $f(\mathbf{x})$ can be written as $P(y|\mathbf{x})$.

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Introduction: Notation and Definitions - Examples

- For a binary classification problem, we have: $\mathcal{Y} = \{-1, +1\}$;
- For a two domain scenario we have:
  - Denoting by $\mathbb{D}_s$ the **source domain** and
  - Denoting by $\mathbb{D}_t$ the **target domain** We have then the:
  - **Source domain labeled data**: $\mathcal{D}_s = \{(\mathbf{x}_{s_i}, y_{s_i})\}_{i=1}^{n_s}$, where
    - $\mathbf{x}_{s_i} \in \mathcal{X}_s$ is the data instance and;
    - $y_{s_i} \in \mathcal{Y}_s$ is the corresponding class label.
  - and the **target domain labeled data**: $\mathcal{D}_t = \{(\mathbf{x}_{t_i}, y_{t_i})\}_{i=1}^{n_t}$, where
    - where the input $\mathbf{x}_{t_i}$ is in $\mathcal{X}_t$ and;
    - $y_{t_i} \in \mathcal{Y}_t$ is the corresponding output.

Introduction: Notation and Definitions

Definition: Transfer Learning

Given a source domain $\mathbb{D}_s$ and a learning task $\mathbb{T}$, a target domain $\mathbb{D}_t$ and a learning task $\mathbb{T}_t$, transfer learning aims to help improve the learning of the target predictive function $f_t(\cdot)$ for the target domain using the knowledge in $\mathbb{D}_s$ and $\mathbb{T}_s$, where $\mathbb{D}_s \neq \mathbb{D}_t$ or $\mathbb{T}_s \neq \mathbb{T}_t$.

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Introduction: Notation and Definitions

Easy Definition: Transfer Learning

Transfer learning uses not only the data in the target task domain as input to the learning algorithm, but also any of the learning process in the source domain, including the training data, models and task description.

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Introduction: Notation and Definitions

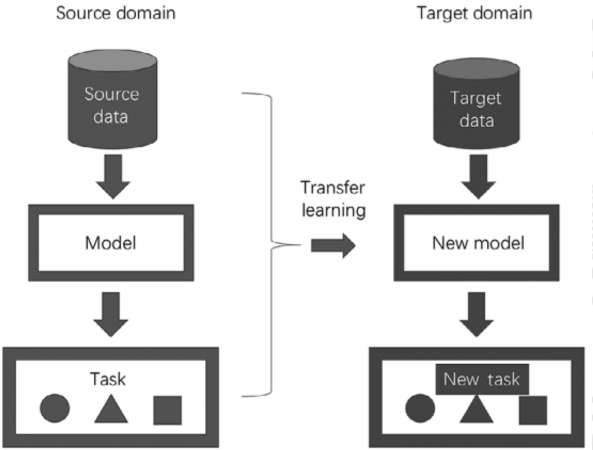

Figura: Source: [Yang 2020]

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Introduction: Applications - Medical Image Analysis

- Small data and expensive labeling: samples obtained (i) using special equipment; (ii) under very private context and (iii) by experts such doctors and radiologists (expansive);
- Complex: 2D or 3D images;
- Imbalanced labels.

Introduction: Notation and Definitions

Definition: Homogeneous Transfer Learning

Given a source domain $\mathbb{D}_s$ and a learning task $\mathbb{T}_s$, a target domain $\mathbb{D}_t$ and a learning task $\mathbb{T}_t$ heterogeneous transfer learning aims to help improve the learning of the target predictive function $f_t(\cdot)$ for $\mathbb{D}_t$ using the knowledge in $\mathbb{D}_s$ and $\mathbb{T}_s$, where $\mathcal{X}_s \cap \mathcal{X}_t \neq \emptyset$ and $\mathcal{Y}_s = \mathcal{Y}_y$, but $\mathbb{P}^{X_s} \neq \mathbb{P}^{X_T}$ or $\mathbb{P} \neq \mathbb{P}$.

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Introduction: Notation and Definitions

Definition: Heterogeneous Transfer Learning

Given a source domain $\mathbb{D}_s$ and a learning task $\mathbb{T}_s$, a target domain $\mathbb{D}_t$ and a learning task $\mathbb{T}_t$, heterogeneous transfer learning aims to help improve the learning of the target predictive function $f_t(\cdot)$ for $\mathbb{D}_t$ using the knowledge in $\mathbb{D}_s$ and $\mathbb{T}_s$, where $\mathcal{X}_s \cap \mathcal{X}_t = \emptyset$ or $\mathcal{Y}_s \neq \mathcal{Y}_t$.

Introduction

- **WHEN NOT to transfer**: when the source domain and the target domain are not related to each other, brute-force transfer may be unsuccessful.
- **WHAT to transfer**: some knowledge is specific for individual domains or tasks, and some knowledge may be common between different domains such that they may help improve performance for the target domain or task.

Approaches: How to Transfer

- **Instance-based algorithms**, where the knowledge transferred corresponds to the weights attached to source instances;
- **Feature-based algorithms**, where the knowledge transferred corresponds to the subspace spanned by the features in the source and target domains;
- **Model-based algorithms**, where the knowledge to be transferred is embedded in part of the source domain models and
- **Relation-based algorithms**, where the knowledge to be transferred corresponds to rules specifying the relations between the entities in the source domain.

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Approaches: How to Transfer

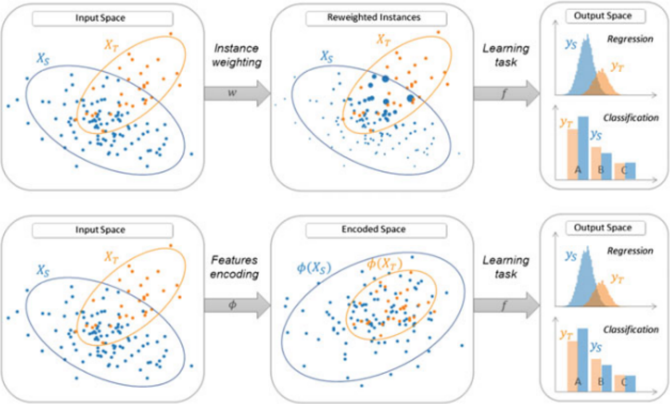

Figura: Illustration of the instance-based (top) and feature-based (bottom) strategies. Source: [Razavi-Far 2020]

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The ADAPT Library

ADAPT (Awesome Domain Adaptation Python Toolbox):

- Is an open-source Python library for transfer learning;
- Provides the implementation of several transfer learning methods;
- Allows users to compare the results of many methods on their particular problem;
- Is suited for Scikit-learn estimator objects (objects which implement fit and predict methods) and Tensorflow models.

The ADAPT Library

- Yang, Qiang and Zhang, Yu and Dai, Wenyuan and Pan Jialin, Sinno. Transfer Learning. Cambrigde University Press. 2020.
- Razavi-Far, Roozbeh et al. Federated and Transfer Learning. Springer. 2020.

Obrigado pela Atenção!

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