

# Learning Transferable Features with Deep Adaptation Networks

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International Conference on Machine Learning, 2015

# Introduction

- Goal: Enhance the transferability of features from task-specific layers
- Proposed a Deep Adaptation Network DAN architecture
  - General features can generalize well to a novel task; however, for specific features they cannot bridge the domain discrepancy
- Some ways to enhance feature transferability:
  - By mean-embedding matching, feature transferability can be enhanced substantially
  - Utilizing multi-layer representations across domains in a reproducing kernel Hilbert space

# Main Breakthrough

- *Generalizes deep CNN to the domain adaptation*
- Deep adaptation of multiple task-specific layers, including output
- Optimal adaptation using multiple kernel two-sample matching

# Deep Learning For Domain Adaptation

- None or very weak supervision in the *target* task (new domain)
  - Target classifier cannot be reliably trained due to over-fitting
  - Fine-tuning is impossible as it requires substantial supervision
- Generalize related supervised source task to the target task
  - Deep networks can learn transferable features for adaptation
- Hard to find big source task for learning deep features from scratch
  - Transfer from deep networks pre-trained on unrelated big dataset
  - Transferring features from distant tasks better than random features

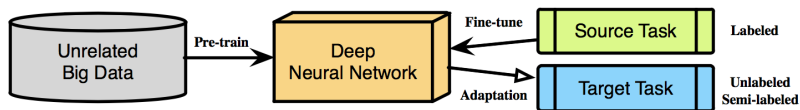


Figure: Deep Learning for Domain Adaptation Workflow

# How Transferable Are Deep Features?

- Transferability is restricted by (Yosinski et al. 2014; Glorot et al. 2011)
- Specialization of higher layer neurons to original task (new task)
- Disentangling of variations in higher layers enlarges task discrepancy
- Transferability of features decreases while task discrepancy increases

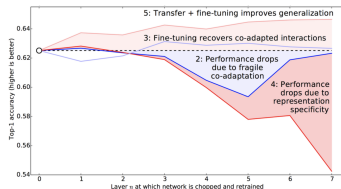


Figure: Transferability of features decreases while task discrepancy increases

# Deep Adaptation Network (DAN)

## Key Observations (AlexNet) (Krizhevsky et al. 2012)

- Comprised of five convolutional layers  $conv1 - conv5$  and three fully connected layers  $fc6 - fc8$
- Convolutional layers learn general features: safely transferable
  - Safely freeze  $conv1 - conv3$  & fine tuned  $conv4 - conv5$
- Fully-connected layers fit task specificity: *NOT* safely transferable
  - Deeply adapt  $fc6 - fc8$  using statistically optimal two-sample matching

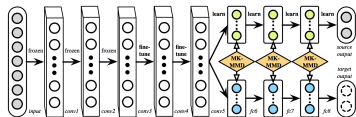


Figure: The DAN architecture for learning transferable features

# Objective Function

## Main Problems)

- Feature transferability decreases with increasing task discrepancy
- Higher layers are tailored to specific tasks, NOT safely transferable
- Adaptation effect may vanish in back-propagation of deep networks

## Deep Adaptation with Optimal Matching

- Deep adaptation: match distributions in multiple layers including output
- Optimal matching: maximize two-sample test of multiple kernels

$$\min_{\Theta} \max_{\kappa} \frac{1}{n_a} \sum_{i=1}^{n_a} J(\theta(x_i^a), y_i^a) + \lambda \sum_{\ell=l_1}^{l_2} d_k^2(D_s^{\ell}, D_t^{\ell}) \quad (1)$$

$\lambda > 0$  is a penalty,  $D_*^{\ell} = \{h_i^{*\ell}\}$  is the  $\ell$ -th layer hidden representation

# MK-MMD

## Theorem (Two-Sample Test (Gretton et al. 2012))

- $p = q$  iff  $d_k^2(p, q) = 0$  (In practice,  $d_k^2(p, q) < \epsilon$ )
- $\max_{k \in \kappa} d_k^2(D_s^\ell, D_t^\ell) \sigma_k^{-2} \Leftrightarrow \min \text{Type II Error } (d_k^2(p, q) < \epsilon \text{ when } p \neq q)$

## Multiple Kernel Maximum Mean Discrepancy (MK-MMD)

$\triangleq$  RKHS distance between kernel embeddings of distributions  $p$  and  $q$

$$d_k^2(p, q) \triangleq \|E_p[\phi(x^s)] - E_q[\phi(x^t)]\|_{\mathcal{H}_k}^2 \quad (2)$$

$k(\mathbf{x}^s, \mathbf{x}^t) = \langle \phi(\mathbf{x}^s), \phi(\mathbf{x}^t) \rangle$  is a convex combination of  $m$  PSD kernels

$$\kappa \triangleq \left\{ k = \sum_{u=1}^m \beta_u k_u : \sum_{u=1}^m \beta_u = 1, \beta_u \geq 0, \forall u \right\} \quad (3)$$