

# A theory of transfer learning with applications to active learning

Liu Yang · Steve Hanneke · Jaime Carbonell

Received: 29 November 2010 / Revised: 3 March 2012 / Accepted: 18 June 2012 /  
Published online: 7 July 2012  
© The Author(s) 2012

**Abstract** We explore a transfer learning setting, in which a finite sequence of target concepts are sampled independently with an unknown distribution from a known family. We study the total number of labeled examples required to learn all targets to an arbitrary specified expected accuracy, focusing on the asymptotics in the number of tasks and the desired accuracy. Our primary interest is formally understanding the fundamental benefits of transfer learning, compared to learning each target independently from the others. Our approach to the transfer problem is general, in the sense that it can be used with a variety of learning protocols. As a particularly interesting application, we study in detail the benefits of transfer for self-verifying active learning; in this setting, we find that the number of labeled examples required for learning with transfer is often significantly smaller than that required for learning each target independently.

**Keywords** Transfer learning · Multi-task learning · Active learning · Statistical learning theory · Bayesian learning · Sample complexity

## 1 Introduction

Transfer learning reuses knowledge from past related tasks to ease the process of learning to perform a new task. The goal of transfer learning is to leverage previous learning and ex-

---

Editor: Tong Zhang.

---

L. Yang (✉)  
Machine Learning Department, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh,  
PA 15213, USA  
e-mail: [liuy@cs.cmu.edu](mailto:liuy@cs.cmu.edu)

S. Hanneke  
Department of Statistics, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA  
e-mail: [shanneke@stat.cmu.edu](mailto:shanneke@stat.cmu.edu)

J. Carbonell  
Language Technologies Institute, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh,  
PA 15213, USA  
e-mail: [jgc@cs.cmu.edu](mailto:jgc@cs.cmu.edu)