Transfer Learning

Transfer learning deals with how systems can quickly adapt themselves to new situations, new tasks and new environments. It gives machine learning systems the ability to leverage auxiliary data and models to help solve target problems when there is only a small amount of data available in the target domain. This makes such systems more reliable and robust, keeping the machine learning model faced with unforeseeable changes from deviating too much from expected performance. At an enterprise level, transfer learning allows knowledge to be reused so experience gained once can be repeatedly applied to the real world.

This self-contained, comprehensive reference text begins by describing the standard algorithms and then demonstrates how these are used in different transfer learning paradigms and applications. It offers a solid grounding for newcomers as well as new insights for seasoned researchers and developers.

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Preface

This book is about the foundations, methods, techniques and applications of transfer learning. Transfer learning deals with how learning systems can quickly adapt themselves to new situations, new tasks and new environments. Transfer learning is a particularly important area of machine learning, which we can understand from several angles. First, the ability to learn from small data seems to be a particularly strong aspect of human intelligence. For example, we observe that babies learn from only a few examples and can quickly and effectively generalize from the few examples to concepts. This ability to learn from small data can be partly explained by the ability of humans to leverage and adapt the previous experience and pretrained models to help solve future target problems. Adaptation is an innate ability of intelligent beings and artificially intelligent agents should certainly be endowed with transfer learning ability.

Second, in machine learning practice, we observe that we are often surrounded with lots of small-sized data sets, which are often isolated and fragmented. Many organizations do not have the ability to collect a huge amount of big data due to a number of constraints that range from resource limitations to organizations interests, and to regulations and concerns for user privacy. This *small-data challenge* is a serious problem faced by many organizations applying AI technology to their problems. Transfer learning is a suitable solution for addressing this challenge because it can leverage many auxiliary data and external models, and adapt them to solve the target problems.

Third, transfer learning can make AI and machine learning systems more reliable and robust. It is often the case that, when building a machine learning model, one cannot foresee all future situations. In machine learning, this problem is often addressed using a technique known as regularization, which leaves room for future changes by limiting the complexity of the models. Transfer learning takes this approach further, by allowing the model to be complex while being prepared for changes when they actually come.

In addition, when facing unforeseeable changes and taking a learned model across domain boundaries, transfer learning still makes sure that the model performance does not deviate from the expected performance too much. In this way, transfer learning allows knowledge to be reused so experience gained once can be repeatedly applied to the real world. From a software system's perspective, if a system is capable of adapting itself via transfer learning in new domains, it is said to be more robust and more reliable when the external environment changes. Such systems are often preferred in engineering practice.

If we continuously apply transfer learning in our machine learning practice, we can obtain a lifelong machine learning system that can draw knowledge from a succession of problem-solving experience, both in a long period of time and from a large variety of tasks. Transfer learning endows an intelligent system with the lifelong learning ability.

Last, but not least, a transfer learning system can be the backbone of a sound business model in which user privacy is taken into serious consideration, such that a pretrained model can be downloaded and adapted at the edge of a computer network without leaking user data accumulated at the edge or from the cloud. By moving the model one way from a server to a client, the privacy at the client side is effectively protected. In addition, by carefully structuring the transfer learning algorithms, private user information on the cloud side can also be protected.

Like AI in general and machine learning in particular, the concept of transfer learning has gone through decades of evolution. From AI's early years, researchers have considered the ability to transfer one's knowledge as one of the fundamental cornerstones of intelligence. Transfer learning is also given different names and explored under different guises, including learning by analogy, case-based reasoning, knowledge reuse and reengineering, lifelong machine learning, never-ending learning and domain adaption, to name a few. Outside of AI and Computer Science, the concept of transfer learning has also been invented under different terms. In the fields of educational theory and learning psychology, for example, the concept of *transfer of learning* has been an important subject in modeling what constitutes effective learning and teaching for educators; it is believed that the best teaching enables the student to learn "how to learn" and adapt the learned knowledge in future situations. Despite different names, their spirits are all similar: to be able to leverage one's past experience to help make more effective decisions in the future.

The study of transfer learning involves many areas of study in science and engineering, including AI, algorithmic theories, probability and statistics, to name a few. The field is also undergoing rapid changes as interests in AI grow, and many new areas contribute to the field. As the first book of its kind in the area, we hope to use it as a tool to help educate the newcomers of machine learning research and application field, as well as a reference book for seasoned machine learning researchers and application developers to use.

The book is partitioned into two parts. Part I presents the foundations of transfer learning. Chapter 1 gives an overview and introduction to transfer learning. Chapters 2–14 introduce various theoretical and algorithmic aspects of transfer learning. Part II, which includes Chapters 15–22, covers many application fields of transfer learning. We give concluding remarks in Chapter 23.

The book is an accumulation of hard research work by a group of researchers that spans over a decade, mainly consisting of Professor Qiang Yang's current and former graduate students, postdoctoral researchers and research associates. We have assigned each chapter to one or more students, and then the four main editors either wrote other chapters or went in depth in each chapter to help refine the content, or did both.

The following is a list of these authors.

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