Supervised and Unsupervised Transfer Learning for Question Answering

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Abstract

Although transfer learning has been shown to be successful for tasks like object and speech recognition, its applicability to question answering (QA) has yet to be well-studied. In this paper, we conduct extensive experiments to investigate the transferability of knowledge learned from a source QA dataset to a target dataset using two QA models. The performance of both models on a TOEFL listening comprehension test (Tseng et al., 2016) and MCTest (Richardson et al., 2013) is significantly improved via a simple transfer learning technique from MovieQA (Tapaswi et al., 2016). In particular, one of the models achieves the state-of-the-art on all target datasets; for the TOEFL listening comprehension test, it outperforms the previous best model by 7%. Finally, we show that transfer learning is helpful even in unsupervised scenarios when correct answers for target QA dataset examples are not available.

1 Introduction

1.1 Question Answering

One of the most important characteristics of an intelligent system is to understand stories as humans do. A story is a sequence of sentences, and can be in the form of plain text (Trischler et al., 2016a; Rajpurkar et al., 2016; Weston et al., 2016; Yang et al., 2015) or spoken content (Tseng et al., 2016), where the latter usually requires the spoken content to be first transcribed into text by automatic speech recognition (ASR), and the model will subsequently process the ASR output. To evaluate the extent of the model’s understanding of the story, it is asked to answer questions about the story. Such a task is referred to as question answering (QA), and has been a long-standing yet challenging problem in natural language processing (NLP).

Several QA scenarios and datasets have been introduced over the past few years. These scenarios differ from each other in many aspects, including the length of the story, the format of the answer, and the size of the training set. In this work, we focus on context-aware multi-choices QA, where the answer to each question can be obtained by referring to its accompanying story, and each question comes with a set of answer choices with only one correct answer. The answer choices are in the form of open, natural language sentences. To correctly answer the question, the model is required to understand and reason about the relationship between the sentences in the story.

1.2 Transfer Learning

Transfer learning (Pan and Yang, 2010), also known as domain adaptation¹, is a vital machine learning technique that aims to store the knowledge learned from one task and apply it to another different but related task, helping either reduce the necessary fine-tuning data size or improve the performance, and has achieved success in numerous domains such as computer vision (Sharif Razavian et al., 2014), ASR (Doulaty et al., 2015; Huang et al., 2013), and NLP (Zhang et al., 2017; Mou et al., 2016). In computer vision, deep neural networks trained on a large-scale image classification dataset such as ImageNet (Russakovsky et al., 2015) have proven to be excellent feature extractors for a broad range of visual tasks such as image captioning (Lu et al., 2017; Karpathy and Fei-Fei, 2015; Fang et al., 2015) and visual question

¹In this paper, we do not distinguish the conceptual difference between transfer learning and domain adaptation. A ‘domain’ in the sense we use throughout this paper is defined by datasets.
answering (Xu and Saenko, 2016; Fukui et al., 2016; Yang et al., 2016; Antol et al., 2015), among others. In NLP, transfer learning has also been successfully applied to tasks like sequence tagging (Yang et al., 2017), syntactic parsing (McClosky et al., 2010) and named entity recognition (Chiticariu et al., 2010), among others.

1.3 Transfer Learning for QA

Although transfer learning has been successfully applied to various domains, its applicability to QA has yet to be well-studied. In this paper, we tackle the TOEFL listening comprehension test (Tseng et al., 2016) and MCTest (Richardson et al., 2013) with a simple transfer learning technique from MovieQA (Tapaswi et al., 2016) using two existing QA models. Both models are pre-trained on MovieQA and then fine-tuned on each target dataset, so that their performance on the two target datasets are significantly improved. In particular, one of the models achieves the state-of-the-art on all target datasets; for the TOEFL listening comprehension test, it outperforms the previous best model by 7%.

Transfer learning without any labeled data from the target domain is referred to as unsupervised transfer learning. Motivated by the success of unsupervised transfer learning for speaker adaptation (Chen et al., 2011; Wallace et al., 2009) and spoken document summarization (Lee et al., 2013), we further investigate whether unsupervised transfer learning is feasible on QA. The work most similar to ours is Min et al. (2017), but they do not study unsupervised transfer learning.

2 Task Descriptions and Approaches

Among several existing QA settings, we focus on multi-choices QA (MCQA) in this work. We are particularly interested in whether a QA model can perform better on one MCQA dataset with knowledge transferred from another MCQA dataset. In Section 2.1, we first formalize the task of MCQA. We then describe the procedures for transfer learning from one dataset to another in Section 2.2. We consider two kinds of settings for transfer learning in this paper, one is supervised and the other is unsupervised, with details in Sections 2.2 and 2.2 respectively.

2.1 Multi-Choices QA

In MCQA, the inputs to the model are a story, a question, and several answer choices. The story, denoted by $S$, is a list of sentences, where each of the sentences is a sequence of words from a vocabulary set $V$. The question and each of the answer choices, denoted by $Q$ and $C$, are both single sentences also composed of words from $V$. The QA model aims to choose one correct answer from multiple answer choices based on the information provided in $S$ and $Q$.

2.2 Transfer Learning

The procedure of transfer learning in this work is straightforward and includes two steps. The first step is to pre-train the model on one MCQA dataset referred to as the source task, which usually contains abundant training data. The second step is to fine-tune the same model on the other MCQA dataset, which is referred to as the target task, that we actually care about, but that usually contains much less training data. The effectiveness of transfer learning is evaluated by the model’s performance on the target task.

Supervised Transfer Learning

In supervised transfer learning, both the source and target datasets provide the correct answer to each question during pre-training and fine-tuning, and the QA model is guided by the correct answer to optimize its objective function in a supervised manner in both stages.

Unsupervised Transfer Learning

We also consider unsupervised transfer learning where the correct answer to each question in the target dataset is not available. In other words, the entire process is supervised during pre-training, but unsupervised during fine-tuning. A self-labeling technique (Lee et al., 2013; Chen et al., 2011; Wallace et al., 2009) is used during fine-tuning on the target dataset. We present the algorithm for unsupervised transfer learning in Algorithm 1.

3 Datasets

We used MovieQA (Tapaswi et al., 2016) as the source MCQA dataset, and TOEFL listening comprehension test (Tseng et al., 2016) and MCTest (Richardson et al., 2013) as two separate target datasets. Examples of the three datasets are shown in Table 1.
### Algorithm 1 Unsupervised QA Transfer Learning

**Input:** Source dataset with correct answer to each question; Target dataset without any answer.

**Output:** Optimal QA model $M^*$

1. Pre-train QA model $M$ on the source dataset.
2. repeat
   3. For each question in the target dataset, use $M$ to predict its answer.
   4. For each question, assign the predicted answer the question as the correct one.
   5. Fine-tune $M$ on the target dataset as usual.
3. until Enough training epochs

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**MovieQA** is a dataset that aims to evaluate automatic story comprehension from both video and text. The dataset provides multiple sources of information such as plot synopses, scripts, subtitles, and video clips that can be used to infer answers. We only used the plot synopses of the dataset, so our setting is the same as pure textual MCQA. The dataset contains 9,848/1,958 train/dev examples; each question comes with a set of five possible answer choices with only one correct answer.

**TOEFL listening comprehension test** is a recently published, very challenging MCQA dataset that contains 717/124/122 train/dev/test examples. There are only four answer choices for each question. The stories in this dataset are in audio form. Each story comes with two transcripts: manual and ASR transcriptions, where the latter is obtained by running the CMU Sphinx recognizer (Walker et al., 2004) on the original audio files. We use TOEFL-manual and TOEFL-ASR to denote the two versions, respectively.

**MCTest** is a collection of 660 elementary-level children’s stories. Each question comes with a set of four answer choices. There are two variants in this dataset: MC160 and MC500. The former contains 280/120/240 train/dev/test examples, while the latter contains 1,200/200/600 train/dev/test examples and is considered more difficult.

The two chosen target datasets are challenging because the documents and questions are complicated, and only small training sets are available. Therefore, it is difficult to train statistical models on only their training sets because the small size limits the number of parameters in the models, and prevents learning any complex language concepts simultaneously with the capacity to answer questions. We demonstrate that we can effectively overcome these difficulties via transfer learning through quantitative results in Section 5.

### 4 QA Neural Network Models

Among numerous models proposed for multiple-choice QA (Trischler et al., 2016b; Fang et al., 2016; Tseng et al., 2016), we adopt the End-to-

| Source Dataset | Target Dataset |
|----------------|----------------|
| MovieQA        | TOEFL          | MCTest         |
| After entering the boathouse, the trio witness Voldemort telling Snape that the elder Wand cannot serve Voldemort until Snape dies ... Before dying, Snape tells Harry to take his memories to the Pensieve ... I just wanted to take a few minutes to meet with everyone to make sure your class presentations for next week are all in order and coming along well. And as you know, you’re supposed to report on some areas of recent research on genetics ... | James the Turtle was always getting in trouble. Sometimes he’d reach into the freezer and empty out all the food ... Then he walked to the fast food restaurant and ordered 15 bags of fries. He didn’t pay, and instead headed home. | What does Snape tell Harry before he dies? Why does the professor meet with the student? What did James do after he ordered the fries? |
| S              | Q              | C1              |
| To bury him in the forest | To find out if the student is interested in taking part in a genetics project | To remember to him for the good deeds |
| C2 | To discuss the student’s experiment on the taste perception | To determine if the student has selected an appropriate topic for his class project |
| C3 | To take his memories to the Pensieve | To explain what the student should focus on for his class presentation |
| C4 | To write down his memories in a book | made up his mind to be a better turtle |

Table 1: Example of the story-question-choices triplet from MovieQA, TOEFL listening comprehension test, and MCTest datasets. S, Q, and C_i denote the story, question, and one of the answer choices, respectively. For MovieQA, each question comes with five answer choices; and for TOEFL and MCTest, each question comes with only four answer choices. The correct answer is marked in bold.
End Memory Network (MemN2N)\textsuperscript{2} (Sukhbaatar et al., 2015) and Query-Based Attention CNN (QACNN)\textsuperscript{3} (Liu et al., 2017), both open-sourced, to conduct the experiments. Below we briefly introduce the two models in Section 4.1 and Section 4.2, respectively. For the details of the models, please refer to the original papers.

4.1 End-to-End Memory Networks

An End-to-End Memory Network (MemN2N) first transforms Q into a vector representation with an embedding layer B. At the same time, all sentences in S are also transformed into two different sentence representations with two additional embedding layers A and C. The first sentence representation is used in conjunction with the question representation to produce an attention-like mechanism that outputs the similarity between each sentence in S and Q. The similarity is then used to weight the second sentence representation. We then obtain the sum of the question representation and the weighted sentence representations over S as \( Q' \). In the original MemN2N, \( Q' \) is decoded to provide the estimation of the probability of being an answer for each word within a fixed set. The word with the highest probability is then selected as the answer. However, in multiple-choice QA, C is in the form of open, natural language sentences instead of a single word. Hence we modify MemN2N by adding an embedding layer F to encode C as a vector representation \( C' \) by averaging the embeddings of words in C. We then compute the similarity between each choice representation \( C' \) and \( Q' \). The choice C with the highest probability is then selected as the answer.

4.2 Query-Based Attention CNN

A Query-Based Attention CNN (QACNN) first uses an embedding layer E to transform S, Q, and C into a word embedding. Then a compare layer generates a story-question similarity map \( SQ \) and a story-choice similarity map \( SC \). The two similarity maps are then passed into a two-stage CNN architecture, where the first stage projects word-level features into a sentence-level one, while the second stage projects sentence-level features into a story-level one. A question-based attention mechanism is applied to each of the two stages on the basis of \( SQ \), yielding choice answer features for each of the choices. Finally, a classifier that consists of two fully-connected layers collects the information from every choice answer feature and outputs the most likely answer. The trainable parameters are the embedding layer E that transforms S, Q, and C into word embeddings, the two-stage CNN \( W_{CNN}^{(1)} \) and \( W_{CNN}^{(2)} \) that integrate information from the word to the sentence level, and from the sentence to the story level, and the two fully-connected layers \( W_{FC}^{(1)} \) and \( W_{FC}^{(2)} \) that make the final prediction. We mention the trainable parameters of the QACNN here because in Section 5 we will conduct experiments to analyze the transferability of the QACNN by fine-tuning some parameters while keeping others fixed.

5 Question Answering Experiments

5.1 Training Details

For pre-training MemN2N and QACNN on MovieQA, we followed the exact same procedure as in Tapaswi et al. (2016) and Liu et al. (2017), respectively. Each model was trained on the training set of the MovieQA task and tuned on the dev set, and the best performing models on the dev set were later fine-tuned on the target dataset. During fine-tuning, the model was also trained on the training set of target datasets and tuned on the dev set, and the performance on the testing set of the target datasets was reported as the final result. We use accuracy as the performance measurement.

5.2 Supervised Transfer Learning

Experimental Results

Table 2 reports the results of our transfer learning on TOEFL-manual, TOEFL-ASR, MC160, and MC500, as well as the performance of the previous best models and several ablations that did not use pre-training or fine-tuning. From Table 2, we have the following observations.

Transfer learning helps. Rows (a) and (f) show results when the models are trained directly on the target datasets without pre-training on MovieQA for QACNN and MemN2N, respectively. Rows (b) and (g) show results when the models are trained only on the MovieQA data. The results achieved in (a), (b), (f) and (g) are worse than their...
Table 2: Results of transfer learning on the target datasets. Rows (a) and (f) are the performance of QACNN and MemN2N trained directly on the target dataset without pre-training on MovieQA, respectively. The number in the parenthesis indicates the accuracy increased via transfer learning (compared to rows (a) and (f)). Rows (b) and (g) are the performance of QACNN and MemN2N pre-trained on MovieQA and directly tested on the target dataset without fine-tuning. The best performance (highest accuracy) for each target dataset is marked in bold. We also include the results of the previous best performing models on the target datasets in the last three rows.

| Model | Training | TOEFL | MCTest |
|-------|----------|-------|--------|
|       |          | manual | ASR    | MC160  | MC500  |
| QACNN | (a) Target Only | 48.9  | 47.5  | 57.5  | 56.4  |
|       | (b) Source Only | 51.2  | 49.2  | 68.1  | 61.5  |
|       | (c) Fine-tuned (1) | 53.4 (4.5) | 51.5 (4.0) | 76.4 (18.9) | 68.7 (12.3) |
|       | (d) Fine-tuned (2) | 56.4 (7.2) | 53.3 (7.8) | 73.8 (16.3) | 72.3 (15.9) |
|       | (e) Fine-tuned (all) | 56.0 (7.1) | 55.1 (7.6) | 69.3 (11.8) | 67.7 (11.3) |
| MemN2N| (f) Target Only | 45.2  | 44.4  | 57.2  | 53.6  |
|       | (g) Source Only | 43.7  | 41.9  | 56.8  | 52.3  |
|       | (h) Fine-tuned | 48.6 (3.4) | 46.6 (2.2) | 66.7 (9.5) | 62.8 (9.2) |
| Fang et al. (2016) | - | 49.1 | 48.8 | - | - |
| Trischler et al. (2016b) | - | - | 74.6 | 71.0 |
| Wang et al. (2015) | - | - | 75.3 | 69.9 |

We conducted experiments to study the relative performance of QACNN parameters to transfer. For the QACNN, the training parameters are $E, W^{(1)}_{CNN}, W^{(2)}_{CNN}, W^{(1)}_{FC}$, and $W^{(2)}_{FC}$ (Section 4.2). To better understand how transfer learning affects the performance of QACNN, we also report the results of keeping some parameters fixed and only fine-tuning other parameters. We choose to fine-tune either only the last fully-connected layer $W^{(2)}_{FC}$ while keeping other parameters fixed (row (c) in Table 2), the last two fully-connected layers $W^{(1)}_{FC}$ and $W^{(2)}_{FC}$ (row (d)), and the entire QACNN (row (e)).

Fine-tuning the entire model is not always best. It is interesting to see that fine-tuning the entire QACNN doesn’t necessarily produce the best result. For MC500, the accuracy of QACNN drops by 4.6% compared to just fine-tuning the last two fully-connected layers (rows (e) vs. (d)). We conjecture that this is due to the amount of training data of the target datasets - the training set of the target dataset is too small, fine-tuning all the parameters of a complex model like QACNN may result in overfitting. This discovery aligns with other domains where transfer learning is well-studied such as object recognition (Yosinski et al., 2014).

A large quantity of mismatched training examples is better than a small training set. It is expected to see that MemN2N trained directly on the target dataset without pre-training on MovieQA outperforms MemN2N pre-trained on MovieQA without fine-tuning on the target dataset (rows (f) vs. (g)), since the model is evaluated on the target dataset. However, for the QACNN this is surprisingly not the case - QACNN pre-trained on MovieQA without fine-tuning on the target dataset outperforms QACNN trained directly on the target dataset without pre-training on MovieQA (rows (b) vs. (a)). We attribute this to the limited size of the target dataset and the complex structure of the QACNN.

Varying the fine-tuning data size

Table 3: Results of varying sizes of the target datasets used for fine-tuning QACNN. The number in the parenthesis indicates the accuracy increase from using the previous percentage for fine-tuning to the current percentage.

| Percentage of the target dataset used for fine-tuning | TOEFL | MCTest |
|-----------------------------------------------------|-------|--------|
|                                                     | manual | ASR    | MC160  | MC500  |
| 0%                                                  | 51.2  | 49.2  | 68.1  | 61.5  |
| 25%                                                 | 53.9 (2.7) | 52.3 (1.3) | 70.3 (2.2) | 65.6 (4.1) |
| 50%                                                 | 54.8 (0.9) | 54.3 (2.1) | 71.9 (1.6) | 68.0 (2.4) |
| 75%                                                 | 55.3 (0.5) | 54.3 (0.8) | 72.5 (0.6) | 71.1 (3.1) |
| 100%                                                | 56.0 (0.7) | 55.1 (0.3) | 73.8 (1.3) | 72.3 (1.2) |

We conducted experiments to study the rela-
tionship between the amount of training data from the target dataset for fine-tuning the model and the performance. We first pre-train the models on MovieQA, then vary the training data size of the target dataset used to fine-tune them. Note that for QACNN, we only fine-tune its last two fully-connected layers instead of the entire model since doing so usually produces the best performance according to Table 2. The results are shown in Table 3. As expected, the more training data is used for fine-tuning, the better the model’s performance is. We also observe that the extent of improvement from using 0% to 25% of target training data is consistently larger than using from 25% to 50%, 50% to 75%, and 75% to 100%. Using the QACNN fine-tuned on TOEFL-manual as an example, the accuracy of the QACNN improves by 2.7% when varying the training size from 0% to 25%, but only improves by 0.9%, 0.5%, and 0.7% when varying the training size from 25% to 50%, 50% to 75%, and 75% to 100%, respectively.

Varying the pre-training data size

Table 4: Results of varying sizes of the MovieQA used for pre-training QACNN. The number in the parenthesis indicates the accuracy increases from using the previous percentage for pre-training to the current percentage.

| Percentage of MovieQA used for pre-training | TOEFL manual | ASR | MC160 | MC500 |
|--------------------------------------------|-------------|-----|-------|-------|
| 0                                          | 48.9        | 47.6| 57.5  | 56.4  |
| 25%                                        | 51.7 (2.8)  | 50.7 (3.1)| 63.8 (6.3)| 62.4 (6.0)|
| 50%                                        | 53.5 (1.8)  | 52.3 (1.6)| 67.3 (3.5)| 66.7 (4.3)|
| 75%                                        | 54.8 (1.3)  | 54.6 (2.3)| 71.2 (3.9)| 70.2 (3.5)|
| 100%                                       | 56.0 (1.2)  | 55.1 (0.5)| 73.8 (2.6)| 72.3 (2.1)|

We also vary the size of MovieQA for pre-training to study how large the source dataset should be to make transfer learning feasible. The results are shown in Table 4. We find that even a small source dataset can help. For example, by using only 25% of MovieQA for pre-training, the accuracy boosts 6.3% on MC160. This is because 25% of MovieQA training set (2462 examples) is still much larger than the training set of MC160 (280 examples). As the size of the source dataset increases, the performance of QACNN continues to improve.

Analysis of the Questions Types

We are interested in understanding what types of questions benefit the most from transfer learning. According to the official guide to the TOEFL test, the questions in TOEFL can be divided into 3 types. Type 1 questions are for basic comprehension of the story. Type 2 questions go beyond basic comprehension, but test the understanding of the functions of utterances or the attitude the speaker expresses. Type 3 questions further require the ability of making connections between different parts of the story, making inferences, drawing conclusions, or forming generalizations. We directly use the split provided by Fang et al. (2016), which contains 81/15/26 Type 1/2/3 questions. We compare the performance of the QACNN and MemN2N on different types of questions in TOEFL-manual with and without pre-training on MovieQA. The results are shown in Figure 1. From Figure 1, we can observe that for both the QACNN and MemN2N, their performance on all three types of questions improves after pre-training, showing that the effectiveness of transfer learning is not limited to some specific type of questions.
(a) Results of TOEFL-manual and TOEFL-ASR

(b) Results of MC160 and MC500

Figure 2: The two figures show the experimental results of unsupervised transfer learning. The ground truths of the questions in the target dataset were not provided when training QACNN and only used for evaluation. The x-axis is the number of epochs for training QACNN, and the y-axis is the corresponding testing accuracy on the target dataset. When training epoch = 0, the performance of QACNN is equivalent to row (b) in Table 2. The horizontal lines, where each line has the same color to its unsupervised counterpart, are the performances of QACNN with supervised transfer learning (row (d) in Table 2), and can be viewed as the upper-bounds for unsupervised transfer learning.

5.3 Unsupervised Transfer Learning

So far, we have studied the property of supervised transfer learning for QA, which means that during pre-training and fine-tuning, both the source and target datasets provide the correct answer for each question. We now conduct unsupervised transfer learning experiments described in Section 2.2, where the answers to the questions in the target dataset are not available. We used QACNN as the model and only the last fully-connected layers were updated during fine-tuning in this experiment. Since the range of the testing accuracy of the TOEFL-series (TOEFL-manual and TOEFL-ASR) is different from that of MCTest (MC160 and MC500), their results are displayed separately in Figure 2(a) and Figure 2(b), respectively.

From Figure 2(a) and Figure 2(b) we can observe that without ground truth in the target dataset for supervised fine-tuning, transfer learning from a source dataset can still improve the performance through a simple iteratively self-labeling mechanism (Algorithm 1). For TOEFL-manual and TOEFL-ASR, QACNN achieves the highest testing accuracy at epoch 7 and 8, outperforming its counterpart without fine-tuning by approximate 4% and 5%, respectively. For MC160 and MC500, the QACNN achieves the peak earlier at epoch 3 and 6, outperforming its counterpart without fine-tuning by about 2% and 6%, respectively. The results also show that the performance of unsupervised transfer learning is still worse than supervised transfer learning, which is not surprising, but the effectiveness of unsupervised transfer learning when limited or no ground truths are provided is validated.

6 Conclusion

In this paper we demonstrate that a simple transfer learning technique can be very useful for the task of multi-choices question answering. We use a QACNN and MemN2N as QA models, with MovieQA as the source task and a TOEFL listening comprehension test and MCTest as the target tasks. By pre-training on MovieQA, the performance of both models on all target datasets improves significantly. The models also require much less training data from the target dataset to achieve similar performance to those without pre-training. We also conduct extensive experiments to study the influence of transfer learning on different types of questions. Finally, we show that unsupervised transfer learning is helpful on QA tasks.

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4We only include the results of QACNN in Table 3, but our observations from the results of MemN2N are very similar to QACNN.
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