

Cost Optimization in Crowdsourcing Translation: Low cost translations made even cheaper

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Abstract

Crowdsourcing makes it possible to create translations at low cost. We proposed two mechanisms to make this process even cheaper while maintaining high translation quality. First, we introduce a ranking selection method that allows us to reduce cost by quickly identifying bad translators after they have translated only a few sentences. This allows us to rank translators, so that we only re-hire good translators and so that we can select the best translations from among good candidates. Second, we develop a model selection method. Our model evaluates the translation quality on a sentence-by-sentence basis, and fits a threshold between acceptable and unacceptable translations. Unlike past work, which always paid for a fixed number of translations of each source sentence and then chose the best from among them, we can decide after seeing a single translation whether it is good enough or not. Our model based selection allows us to reduce cost by reducing the number of redundant translations that we solicit.

allel corpora to train translation models. Crowdsourcing's low costs has made it possible to hire people to create sufficient volumes of translation in order to train SMT systems (for example, Zbib et al. (2013), Zbib et al. (2012), Post et al. (2012), Ambati and Vogel (2010)).

However, crowdsourcing is not perfect, and one of its most pressing challenges is how to ensure the quality of the data that is created by it. Unlike in more traditional employment scenarios, where annotators are pre-vetted and their skills are clear, in crowdsourcing very little is known about the annotators. They are not professional translators, and there are no built-in mechanisms for testing their language skills. They complete tasks without any oversight. Thus, translations produced via crowdsourcing may be low quality. Previous work has addressed this problem, showing that non-professional translators hired on Amazon Mechanical Turk (MTurk) can achieve professional-level quality, by soliciting multiple translations of each source sentence and then choosing the best translation (Zaidan and Callison-Burch, 2011).

1 Introduction

Crowdsourcing is a promising new mechanism for collecting large volumes of annotated data at low cost. Many NLP researchers have focused on creating speech and language data through crowdsourcing (for example, Snow et al. (2008), Callison-Burch and Dredze (2010) and others). One NLP application that has been the focus of crowdsourced data collection is statistical machine translation (SMT) which requires large bilingual sentence-aligned par-

In this paper we focus on a different aspect of crowdsourcing from Zaidan and Callison-Burch (2011). We attempt to achieve the same high quality while **minimizing the associated costs**. We reduce the costs associated with both professional and non-professional translations. Professional translations are used as calibration data for crowdsourcing. We show that using a single reference is as effective as using multiple references. To reduce costs for non-professional translations, we propose two complementary methods: (1) We reduce the number of

worker we hire, and retain only high quality translators by quickly identifying and filtering out workers who produce low quality translations. (2) We reduce the number of translations that we solicit for each source sentence. Instead of soliciting a fixed number of translations for each foreign sentence, we stop soliciting translations after we get an acceptable one. We do so by building models to distinguish between acceptable translations and unacceptable ones.

Our work stands in contrast with Zaidan and Callison-Burch (2011) who had no model of annotator quality, and who always solicited and paid for a fixed number of translations of each source segment.

In this paper we demonstrate that

- Workers can be ranked by their quality with high correlation against a gold standard ranking, using linear regression and a variety of features, or initially testing them using a small amount of calibration data with known professional translations.
- This ranking can be established after observing very small amounts of data (reaching ρ of 0.88 after seeing the translations of only 20 sentences from each worker). Therefore, bad workers can be filtered out quickly.
- Our models can predict whether a given translation is acceptable with high accuracy, substantially reducing the number of redundant translations needed for every source segment.
- We can achieve a similar BLEU score as Zaidan and Callison-Burch (2011) at half the cost using our model selection method.

2 Problem Setup

[Put a few sentences here to give an outline of this section.]

2.1 Datasets

We use the data collected by Zaidan and Callison-Burch (2011) through Amazon’s Mechanical Turk. They hired Turkers to translate 1792 Urdu sentences from the 2009 NIST Urdu-English Open Machine Translation Evaluation set¹. Workers also filled out

a survey about their language skills and their countries of origin. A total of 51 Turkers contributed translations. Each Urdu sentence was translated by 4 Turkers and 4 professional translators.

2.2 Evaluation Metric for Translation Quality

For this data set we have access to 4 sets of professional translations, which were created by different translation agencies hired by the LDC. While minimizing costs, we want to ensure that the quality of the translations does not suffer. To evaluate translation quality, we compute the quality of selected non-professional translations using the BLEU score (Papineni et al., 2002) against all professional translations. However, to reduce cost of computing the calibration feature and labeling each training sample by its BLEU score, we randomly select **only one** professional translation as reference to calculate the BLEU score.

2.3 Evaluation Metric for Cost

[This subsection need to be more concise, and merge the following two subsections of the previous draft together: the one subsection about the exact prices and the one subsection of the cost formula.]

Throughout this paper we will analyze the cost savings of the various methods that we propose. To make it clear how we compute the savings, we define that the unit cost for one professional reference as C_p , and the unit cost for one non-professional translation as C_{np} . Suppose we have N_p source sentences with α matching professional translations for each of them and N_{np} source sentences with β matching non-professional translations for each of them, the total cost C is:

$$C = \alpha \cdot N_p \cdot C_p + \beta \cdot N_{np} \cdot C_{np}$$

where α and β represent the level of redundancy of professional and non-professional translations respectively, and in our case, basically $\alpha = \beta = 4$. The costs associated with professional translations result from the calibration data that is used to estimate the goodness of the non-professional translation. This will be a fraction of the total data being translated. Conversely, the number of non-professional translations will typically exceed the total number of sentences being translated, because

¹LDC Catalog number LDC2010T23

we particularly solicit multiple (redundant) translations of the same input sentence from different non-professionals, and then pick the best translation.

===

Compared to the cost of professional translations, the cost of crowdsourced translations is already low. Zaidan and Callison-Burch (2011) paid \$0.10 per sentence. The cost to translate each of the sentences in the Urdu data set once was \$179.20, plus a 10% commission to Amazon. The major cost involved with their method is the need to redundantly translate every source sentence. Every sentence in their set was independently translated by 4 workers. So the total cost to create the translations in their data set was \$716.80 (+10%). Although <\$1,000 is certainly a modest amount, if we want to collect data at a very large scale, the cost for non-professional translations will dramatically increase.

Another major component cost of the Zaidan and Callison-Burch (2011) is the need for some amount of professionally-translated data, used to calibrate the goodness of the non-professional Turker translators. Zaidan and Callison-Burch (2011) vary the amount of calibration data used. The minimum amount is 10% of the data set. If we estimate the cost of professional translation at \$6.03 per sentence (\$0.3 per word \times 20.1 words per sentence), then the cost of the calibration data is \$4,322.30.

We attempt to minimize cost by reducing the number of translations needed for each sentence, and reducing the amount of professionally-translated calibration data. The lower-bound on cost is \$179.20, for single translations from Turkers with no calibration data. The upperbound for the non-professionals cost is \$716.80 and the upperbound for total cost is \$5,039.10 (\$716.80 + \$4,322.30 at 10% calibration).

3 Estimating Translation Quality

[Merge the following section with part of Omar’s paper to explain the model and features clearly, make it self-contained]

Zaidan and Callison-Burch (2011) used the features in order to train models to select the best translation from 4 candidate translations, and compared the Turkers’ translation quality to professional quality. They extracted a number of features

from the translations and workers’ self-reported language skills in order to predict the best translations. These features included 9 sentence-level features, 15 worker-level features that aggregate over the sentence-level features, plus features based on workers’ language abilities and their location, and a set of 3 features based on a second-pass HIT where monolingual English speakers ranked the translations. Finally, they integrate a worker calibration feature, that computes a BLEU score for each Turker by comparing a fraction of their translations against the professional translations.

=== In addition to the features that (Zaidan and Callison-Burch, 2011) used, we introduce a new bilingual feature. We use the IBM Model 1 to construct the word alignment with probabilities between Urdu and English. For each foreign sentence, we calculate the word alignment feature by averaging the alignment probabilities of all words in Urdu sentence.

To evaluate each translation, we use a linear regression model to predict a score ($\hat{y} \in R$) for an input translation t .

$$\hat{y} = \hat{w} \cdot f(t)$$

where \hat{w} is the associated weight vector and $f(t)$ is the feature vector of the translation t .

4 Reducing the Number of Translators

Our problem definition of the cost optimization task is: given a small portion of translation data (non-professionals and professionals), we want to identify bad workers and unacceptable translations to reduce cost by avoiding hiring bad workers continually or purchasing redundant translations after we get acceptable ones. At the same time, we want to maintain in high translation quality.

[Add a few more sentences here of the two methods used.]

4.1 Workers are consistently good (or bad) over time

Figure 1 illustrates the consistency of workers’ performance by showing the gold-standard ranking of Turkers created by computing their BLEU scores compared to professionals for all of the translations that they submitted, along with the number of HITs

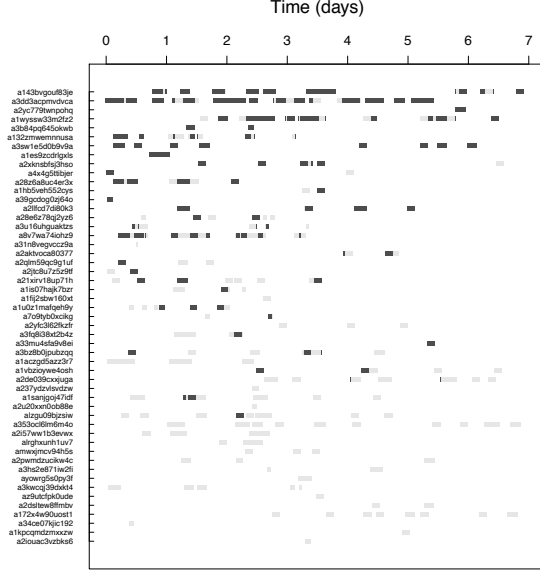


Figure 1: A time-series plot of all of the translations produced by Turkers (identified by their WorkerID serial number). Turkers are sorted based on the gold-standard ranking against professionals, with the best translators on top on y-axis. Each tick represent a single translation HIT, and depicts the HIT’s BLEU score (color) and its size/number of sentences (thickness). We use the average BLEU score for each HIT and show its tick in black if its BLEU score is higher than the median and in light grey otherwise.

produced by each worker and their timing information. From this graph we see that that most workers’ performance stays consistent as time passes. Good translators tend to produce consistently good translations and bad workers rarely produce good translations.

4.2 Automatically Ranking Translators

Since workers’ performance is consistent, workers’ rankings are sufficiently accurate to reflect the quality of translations provided by them and we can select the translation which is provided by the worker with the best rank. We propose two methods to rank workers and select translations.

We present ranking selection methods to compute ranks of workers from a small portion of work they submitted. We filter out bad workers and select the best translation from translations provided by surviving workers.

Ranking workers using a model We use a linear regression model to score each translation and rank workers by their model predicted performance. The model predicted score for translation t is defined as $M(t)$. The model predicted performance of the worker w is:

$$Performance(w) = \frac{\sum_{t \in T_w} M(t)}{|T_w|}$$

where T_w is the set of translations completed by w . After we rank workers, we keep top workers in the list and select translation provided by the worker with best rank among top workers.

Ranking workers using their first k translations

Rather than using a model to rank workers, we take the first few translations provided by each Turker and compare them to the professional translations of those sentences. We rank workers based on this gold standard data and discard bad workers.

4.3 Experiments

We report ranking’s correlation to gold standard ranking and translation quality for both two methods.

4.3.1 Baselines

We evaluate ranking quality in Spearman’s correlation(ρ) compared with the gold standard ranking of workers. We score each Turker based on the average BLEU score of all his/her translations against professional references and we rank Turkers by their scores. We use the gold standard ranking as the ranking oracle and the upper-bound correlation is 1. In addition, we set two baselines for ranking correlation(ρ) for our proposed approaches. For the first baseline, we choose the MERT(Och, 2003) baseline, which achieves a correlation of 0.67 when trained on ranking features. This is the highest correlation that MERT achieves across all feature sets. The second baseline is a simpler baseline that reserves 10% of the data for calibration, and computes a ranking of translators based on their BLEU scores against professionals over this calibration set, the correlation reaches 0.68.

For translation quality evaluation, we set the gold standard ranking selection method as the oracle method, in which we select translation provided by

the worker with best rank in gold standard ranking, and the BLEU score achieved is denoted as B_{gold} . Besides, we set the random selection method as the baseline method which randomly select a translation from all candidates for each source sentence.

4.3.2 Ranking workers using a model

We use 10% of data to train a linear regression model to rank workers and select best translation by workers' ranking. Table 1 shows that our model achieves the highest BLEU score of 38.37 when trained on all features. If we calculate calibration feature and training sample label against only one reference rather than 4 references, we achieve a BLEU score of 37.52 with a correlation of 0.71 which is higher than two baselines. To further reduce cost, we retain only top 25% workers and select the translation with the best rank provided by top workers. We achieve a BLEU score of 37.09 while B_{gold} is 38.51 and the baseline is 29.95. The cost is:

$$C = \frac{\alpha}{4} \cdot \frac{1}{10} N_p \cdot C_p + \frac{\beta}{4} \cdot \frac{9}{10} N_{np} \cdot C_{np} \\ = 1,241.86(\$)$$

Thus, we can achieve a comparable translation quality by spending almost only 25% of money with a quality loss of 1.53 in BLEU.

Feature Set	ρ	BLEU
(S)entence features	0.69	36.66
(W)orker features	0.65	36.92
(R)anking features	0.79	36.94
Calibration features	0.79	38.27
Calibration features*	0.68	37.22
S+W+R features	0.78	37.39
S+W+R+Bilingual features	0.80	37.59
All features	0.84	38.37
All features*	0.71	37.52

Table 1: Spearman's correlation(ρ) and translation quality of model predicted ranking selection method for linear regression model trained using different feature sets. We don't filter out bad workers when selecting the best translation. * indicates that we choose **only one** professional reference to calculate the BLEU score as calibration feature and the true label of a training sample while in other cases, we use 4 references to calculate BLEU score.

4.3.3 Ranking workers using their first k translations

Without using any model, we rank workers using their first k translations and select best translations based on rankings of the top 25% workers. To evaluate this method, we created several test sets. Each test set excluded any item that was used to rank the workers, or which did not have any translations from the top 25% of workers according to our predicted rankings. We therefore have *different test sets* for each value of k. This makes the results slightly more difficult to analyze than in normal experiments, although the trends are still clear. Formally, we define the test set for first k sentences as T_k and for each source sentence $s \in T_k$:

$$\{s \mid (C(s) \cap S_k = \emptyset) \wedge (C(s) \cap S_w \neq \emptyset)\}$$

where $C(s)$ is the translating candidates set of the source sentence s , S_k is the translation set consists of each worker's first k translations and S_w is the translation set consists of translations provided by selected workers (some top ranking workers). Table

Proportion of Calibration Data		ρ^+	ρ^*
First k sentences	Percentage		
1	0.7%	0.57	0.41
2	1.3%	0.62	0.48
3	2.0%	0.69	0.59
4	2.7%	0.72	0.59
5	3.3%	0.78	0.69
6	4.0%	0.80	0.70
7	4.7%	0.79	0.71
8	5.3%	0.81	0.69
9	6.0%	0.84	0.77
10	6.6%	0.84	0.76
20	13.3%	0.93	0.88
30	19.9%	0.96	0.93
40	26.6%	0.97	0.95
50	33.2%	0.98	0.95
60	39.8%	0.99	0.94

Table 2: Spearman's Correlations for calibration data in different proportion. * indicates that the calibration is computed against **only one** reference while + indicates that the calibration is computed against 4 references.

2 shows the results of Spearman's correlations for

different value of K . Compared with 4-reference calibration, we achieve very strong correlation when calibrating the workers using one reference based on the translations of their first 40 sentences. Even we only use the first 20 sentences to evaluate and rank workers, the correlation (ρ^*) is close to 0.90. Consequently, we can decide whether to continue to hire a worker in a very short time after analyzing the first k sentences ($k \leq 20$) provided by each worker.

Figure 2 shows the BLEU score when we select the top 25% workers from the ranking list based on the performance of first k sentences. As a comparison, we also plotted the BLEU scores for random selection and the BLEU score for selection based on the gold standard ranking (B_{gold}). As we increase the number of sentences we use to rank workers, the BLEU score we get from the ranking approaches B_{gold} . Surprisingly, we see that when only a small part of sentences (say 20 sentences) for each worker are used in ranking, the ranking list is quite similar to the gold standard ranking list and the BLEU score is very close to the BLEU score get by gold standard ranking.

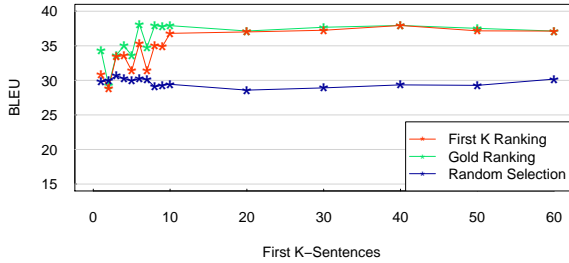


Figure 2: The BLEU score for selecting the best translation by the top 25% Turkers’ ranking based on the first k sentences (red line). The green line shows the BLEU score for selecting the best translation by the gold standard ranking. The dark blue line shows the BLEU score for selecting translation randomly.

If we use the first 20 sentences to rank workers, the correlation is 0.88 and the BLEU score achieved is 37.01 while B_{gold} is 37.14. The difference between these two scores is 0.13 and the cost is:

$$C = \frac{\alpha}{4} \cdot (0.133 \cdot N_p) \cdot C_p + \frac{\beta}{4} \cdot (0.867 \cdot N_{np}) \cdot C_{np} = 1,592.53(\$)$$

We can achieve almost the same translation as the oracle method with only spending 32% of the total cost.

5 Reducing the Number of Translations

We present the model selection method to decide whether a translation is ‘good enough,’ in which case we don’t need to pay for another redundant translation of the source sentence. Additionally, we make it possible to control the translation selected from a partial translation set to a proportion (δ) of the upper bound of BLEU score. The upper bound of BLEU score is computed on best translations selected from the full translation set of training data. Algorithm 1 details the process. After we get the θ (threshold between acceptable and unacceptable translations) for a specific value of δ (say 95%), for given a new translation, we score it by our model and if its score is higher than θ , we stop soliciting another translation. Otherwise, we continually solicit translations.

5.1 Translation Quality Competition

We divide data into training set(10%), validation set(10%) and testing set(80%). Each sample in training and validating set is labeled and calibrated by BLEU score calculated against **only one** reference. The step we set to sweep θ in validating process is 0.01 and the *upperbound* is set to be 0.41 empirically. We vary the value of δ from 90% to 100% and the results we reported are based on five-fold cross validation.

We set a competitive method to compete with, which is revised from the framework of model selection mechanism with two different points: (1) we label and calibrate each sample in training and validating set using BLEU computed against four references; (2) we select translation from all candidates for each source sentence. We get a surprisingly high BLEU score of 40.13 using this method with a high cost over \$9,000 (\$716.80 + \$8,644.6 for 20% calibration). In addition, we set the random selec-

Algorithm 1 Model selection algorithm

Input: δ , the proportion of the upperbound of BLEU score; a training set $S = \{(x_{i,j}^s, y_{i,j}^s)_{j=1}^4\}_{i=1}^n$ and a validation set $V = \{(x_{i,j}^v, y_{i,j}^v)_{j=1}^4\}_{i=1}^n$ where $x_{i,j}$ is the feature vector for the j th translation of the source sentence s_i and $y_{i,j}$ is the label for $x_{i,j}$.

Output: θ , the threshold between acceptable and unacceptable translations; $m(x)$, a linear regression model.

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1: initialize  $\theta \leftarrow 0, m(x) \leftarrow \emptyset$ 
2:  $m'(x) \leftarrow$  train a linear regression model on  $T$ 
3:  $maxbleu \leftarrow$  use  $m'(x)$  select best translations
   for each  $s_i \in T$  and record the highest model
   predicted BLEU score
4:  $upperbound \leftarrow$  set an upper-bound BLEU
   score empirically
5: while  $\theta \neq maxbleu$  do
6:   for  $i \leftarrow 1$  to  $n$  do
7:     for  $j \leftarrow 1$  to 4 do
8:       if  $m'(x_{i,j}^v) > \theta \wedge j < 4$  then select
        $x_{i,j}^v$  for  $s_i$  and break
9:       if  $j == 4$  then select  $x_{i,j}^v$  for  $s_i$ 
10:     $q \leftarrow$  calculate translation quality for  $V$ 
11:    if  $q > \delta \cdot upperbound$  then break
12:    else  $\theta = \theta + stepsize$ 
13:  $m \leftarrow$  train a linear regression model on  $S \cup V$ 
14: Return:  $\theta$  and model  $m(x)$ 

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tion baseline and the corresponding BLEU score is 29.56.

Table 3 shows the results for model selection method. We get comparable translation quality against our competing method with a much lower cost. If we set δ as 0.95, comparing two method, the difference in translation quality is 1.7 and for each source sentence, we almost avoid paying one redundant translation. The cost is:

$$\begin{aligned}
C &= \frac{\alpha}{4} \cdot \frac{2}{10} N_p \cdot C_p + \frac{3.12}{4} \beta \cdot \frac{8}{10} N_{np} \cdot C_{np} \\
&= 2,608.43(\$)
\end{aligned}$$

which is 52% of the original total cost and 28% of the cost of our competing method.

$\delta(\%)$	BLEU Score	# of Trans.
90	37.04	2.11
91	37.20	2.19
92	37.77	2.54
93	37.79	2.61
94	38.31	3.07
95	38.43	3.12
96	38.65	3.44
97	38.71	3.39
98	39.17	3.88
99	39.32	3.99
100	39.36	3.99

Table 3: The relation among the δ (the proportion of the BLEU score’s upper bound), the BLEU score for translations selected by models from partial sets and the averaged size of translation candidates set for each source sentence (# of Trans).

5.2 Cost Analysis

We have introduced several ways of lowering the costs associated with crowdsourcing translations:

- We show that we can quickly identify bad translators, either with a model designed to rank them, or by ranking them by having them first translate a small number of sentences with gold standard translations. The cost savings for non-professionals here comes from not hiring bad workers.
- After we have collected one translation of a source sentence, we consult a model that predicts whether its quality is sufficiently high or whether we should pay to have the sentence re-translated. The cost savings for non-professionals here comes from reducing the number of redundant translations.
- In both cases we need a some amount of professionally translated materials to use as a gold standard for calibration. The cost savings for professionals come from reducing the referencing translations to calibrate each data sample.

In all cases, there is a trade-off between lowering our costs and producing high quality translations. Figure 3 plots the cost versus the BLEU scores for the different configurations that we experimented with.

In Figure 3-(a) the increasing costs are a function of how many sentences we use to rank the translators. Here we use no model, and simply rank the translators by their BLEU score against a small amount of gold standard data. The quality peaks at 37.9 BLEU after \$3,000. We are able to rank the translators with high accuracy and achieve a relative high BLEU score by paying for a comparatively small number of professional translations to use as calibration. From our experiments, 10-20 professionally translated sentences seems like a reasonable number.

Figure 3-(b) uses a model to determine whether to purchase another translation. This model allows us to significantly improve the overall translation quality to a BLEU score of nearly 40, for a final cost of \$2,700.

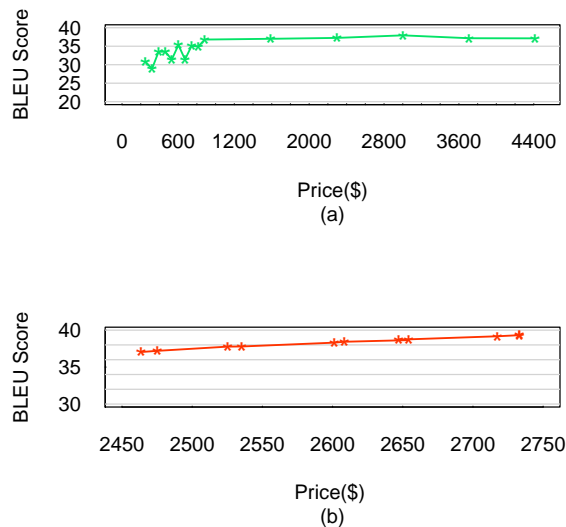


Figure 3: The Relationship between BLEU score and costs. In Figure (a), the red line shows the relationship between BLEU score and the total costs (professional and non-professional) for the ranking based approach. Figure (b) shows the relationship between BLEU score and the total costs for model-based approach.

6 Related Work

Sheng et al. (2008)’s work on repeated labeling presents a way of solving the problems of uncertainty in labeling. Since we cannot always get high-quality labeled data samples with relatively

low costs in reality, to keep the model trained on noisy labeled data having a high accuracy in predicting, Sheng et al. (2008) proposed a framework for repeated-labeling that resolves the uncertainty in labeling via majority voting. The experimental results show that a model’s predicting accuracy is improved even if labels in its training data are noisy and of imperfect quality. As long as the integrated quality (the probability of the integrated labeling being correct) is higher than 0.5, repeated labeling benefits model training.

Passonneau and Carpenter (2013) created a Bayesian model of annotation and they applied to the problem of word sense annotation. Passonneau and Carpenter (2013) also proposed an approach to detect and avoid spam workers. They measured the performance of worker by comparing worker’s labels to the current majority labels and worker with bad performance would be blocked. However, this approach suffered from 2 shortcomings: (1) Sometimes majority labels may not reflect the ground truth label. (2) They didn’t figure out how much data(HITs) is needed to evaluate a worker’s performance. Although they could find the spam after the fact, it was a post-hoc analysis, so they had already paid for that worker and wasted the money.

Lin et al. (2014) examined the relationship between worker accuracy and budget in the context of using crowdsourcing to train a machine learning classifier. They show that if the goal is to train a classifier on the labels, that the properties of the classifier will determine whether it is better to re-label data (resulting in higher quality labels) or get more single labeled items (of lower quality). They showed that classifiers with weak inductive bias benefit more from relabeling, and that relabeling is more important when worker accuracy is low (barely higher than 0.5).

Novotney and Callison-Burch (2010) showed a similar result for training an automatic speech recognition (ASR) system. When creating training data for an ASR system, given a fixed budget. Their system’s accuracy was higher when it is trained on more low quality transcription data compared to when it was trained on fewer high quality transcriptions.

7 Conclusion

In this paper, we propose two mechanisms to optimize cost: the ranking selection method and the model selection method. They have different applicable scenarios. The ranking selection method is a very simple method without any model training. This approach is inspired by the intuition that workers' performance is consistent. The ranking selection method is suitable for crowdsourcing tasks which do not have specific requirements about the quality of the translations, or when the data collection is being performed by a requester who does not have sufficient background in machine learning in order to train a model, or when only very limited amounts of gold standard data are available. The model selection method works if there exists a specific requirement that the quality control must reach a certain threshold, or when more data needs to be collected. This model is most effective when reasonable amounts of pre-existing professional translations are available for setting the models threshold. Its major cost reduction comes from dramatically reducing the amount of non-professional data to maintain the same quality.

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