

# Joint Training of Classification and Similarity Models for Intention Detection in Task-specific Chatbot

Anonymous ACL-IJCNLP submission

## Abstract

Task-specific chatbot systems have gained many important applications, such as Siri, Google home, and customer service systems, etc. One essential technique underlying these applications is to detect the real intention behind a user's input. Intention detection, assuming only one intention in a user's input here, can be regarded as a short text classification problem. In practice, the number of intentions can be hundreds of thousands, as opposed to a few number in the traditional text classification problem; creating enough training data from tons of raw user logs with miscellaneous information is not trivial, and generally only 10 to 20 samples per intention are available in the early stage. Thus, how to train an effective short-text classification model with limited labeled data in such a practical and important application is critical. In this work, we propose a novel model, called similarity model fused with classification model (SFC), which combines both the performance of a classification model and the ability of supporting out-of-domain data from a similarity model in the framework of multi-task training. We conduct extensive experiments on 4 public and 1 private datasets. Experimental results show that our new model outperforms very strong baselines (i.e., BERT, RoBERTa and ALBERT based pretrained models) by over 2 percent-ages in average F1 score.

## 1 Introduction

Task-specific conversational chatbot (Wen et al., 2016) has been applied into many practical products. One typical example is the chatbot that shares the working burden of human customer service agents responsible for customers' questions. Another one is intelligent speakers, e.g. Siri, Google home. Regardless of whether these conversations belong to single or multi-round, an essential technique underlying this type of chatbot is to identify

the real intention behind a user's question or reply. The detected intention with its associated information is then mapped into a predefined dialog logic graph, from which a suitable response is returned. This is the main difference from a free chatbot.

Intention detection in task-specific chatbot is a challenging task due to its inherent properties. First, a customer's utterance within a conversation is usually quite short. Since it does not contain enough information, short texts (Song et al., 2014) are thought to be more ambiguous compared to long texts such as paragraphs or documents, posing a great challenge (Chen et al., 2019a) for classification task (Phan et al., 2008; Yan et al., 2009; Hua et al., 2015). Second, in the initial stage of building a chatbot, it is often rather hard to collect sufficient labeled data to train a good model. Developers have to examine tons of real system logs for typical user's utterances, and then label them with expected intentions. Therefore, to build a task-specific chatbot with high performance, it is essential to solve the challenge of short-text classification (Sriram et al., 2010) problem under few-shot setting (Yu et al., 2018).

Generally there are two kinds of approaches to address this problem.

The first one, *text classification*, includes classic long text classification and short text classification in this scenario. Besides traditional machine learning models like SVM (Suykens and Vandewalle, 1999), boosting tree (Tu, 2005), many work (Wen et al., 2016) choose neural network such as convolutional neural networks (CNNs) (Kim, 2014; Zhang et al., 2015; Conneau et al., 2016) and long short term memory networks (LSTMs) (Mousa and Schuller, 2017; Liu et al., 2016) to accomplish the task of extracting semantic features from limited amount of words. Another two interesting lines of work, label-word joint models, and joint NER and classification are discussed in the related work of

appendix. Recently, pre-trained language models on large corpus like BERT (Devlin et al., 2018) and RoBERTa (Liu et al., 2019c) has been proven more powerful in solving many NLP tasks including short-text classification (Madabushi et al., 2020). Especially for few-shot scenarios (Yu et al., 2018), pre-trained models based on transformers (Vaswani et al., 2017) tends to be more helpful to alleviate the dearth of training data.

The second one, *text similarity model*, is usually employed to calculate how similar between an input text and a historical text in the repository. The associated label of the most similar historical text is returned as the label of the text to query (Jafarpour et al., 2010; Leuski and Traum, 2011). A popular and effective methodology is adopting BERT (Devlin et al., 2018) and other pretrained models (Liu et al., 2019c) to model the similarity model as a binary classification problem.

Despite the success of these two approaches, they still have some limitations. Regarding the *text classification model*, when the labeled data in current domain is insufficient, it is quite hard to adopt labeled data from other domains, as their label definitions are often incompatible to each other. Though we can use some paraphrasing methods, e.g., machine translation based, to expand the labeled data, the resulting benefit is still limited. Regarding the *similarity model*, the foremost advantage is it does not pose any restriction on label definition in a domain, as it merely models the similarity of two input texts. Thus, we may borrow plenty of extra data to help the similarity model training in current domain (Sun et al., 2019). Yet, its biggest disadvantage is its optimization loss differs from that in a specific task. This always lead to a suboptimal model.

The above limitations motivate us to propose a system that takes both the performance of a classification model and the ability of supporting out-of-domain data from a similarity model. We call our system as SFC, short for similarity model fused with classification model, shown in Fig. 1. We further bring in multi-task learning (Caruana, 1993; Collobert and Weston, 2008; Liu et al., 2019a) to train SFC. Our basic idea consists of two stages. In the first stage, we use an auxiliary model to select top-K most possible labels for an input. This model can be an elastic search (Divya and Goyal, 2013) or a text classification model trained on current task-specific chatbot data. In the second stage, we

build a classification model whose main modules are similarity models. Then, this structure derives two goals to train towards, the classification loss for our application, and the similarity loss for the main modules. When the two stages are independently optimized, we call *two-stage SFC*.

We further find that the quality of the output from the first stage might limit the final performance of the system, since the candidate labels for an input is fixed in the whole multi-task training process. This observation motivates us to further improve the two-stage SFC into a joint training setting, called *joint SFC*. In this way, the candidate texts associated with the top-K classes also become dynamic, and the text classification model in the first stage will also be further optimized to provide better top-K results by the final training loss.

Experiment results from 4 public and 1 private short-text classification datasets, show that our proposed SFC joint system can achieve significant and consistent improvements over strong baselines, especially in the low resource settings.

## 2 Methodology

In this section, we describe our proposed SFC method, which includes the basic two-stage SFC and its more compact version joint SFC.

### 2.1 Two-stage SFC

It consists of the following two independent stages in charge of different jobs.

#### Stage 1: classification model for providing top-K candidate class labels

We can use any auxiliary text classification model or tool, such as Term Frequency-Inverse Document Frequency (TF-IDF) retrieval, to provide top-K most related class labels. These selected class labels will later be used to sample sentence pairs of both positive and negative samples for stage 2.

In this work, we choose pretrained models to fine tune on our data. Due to the excellent performance of RoBERTa in this task, compared to other pretrained models, we use RoBERTa as the encoder of classification model in our setting.

Given a data point  $x_i$  with class label  $y_i$  from dataset  $\mathcal{D}$ , we take the final hidden state  $h_i$  of the first token [CLS] encoded by RoBERTa as the representation for the whole sequence of  $x_i$ . Then a linear layer is followed to output probabilistic distribution of class labels,  $\text{softmax}(W^C h_i + b^C) = \text{softmax}(\Phi_i^C)$ , where  $W^C$  and  $b^C$  are trainable

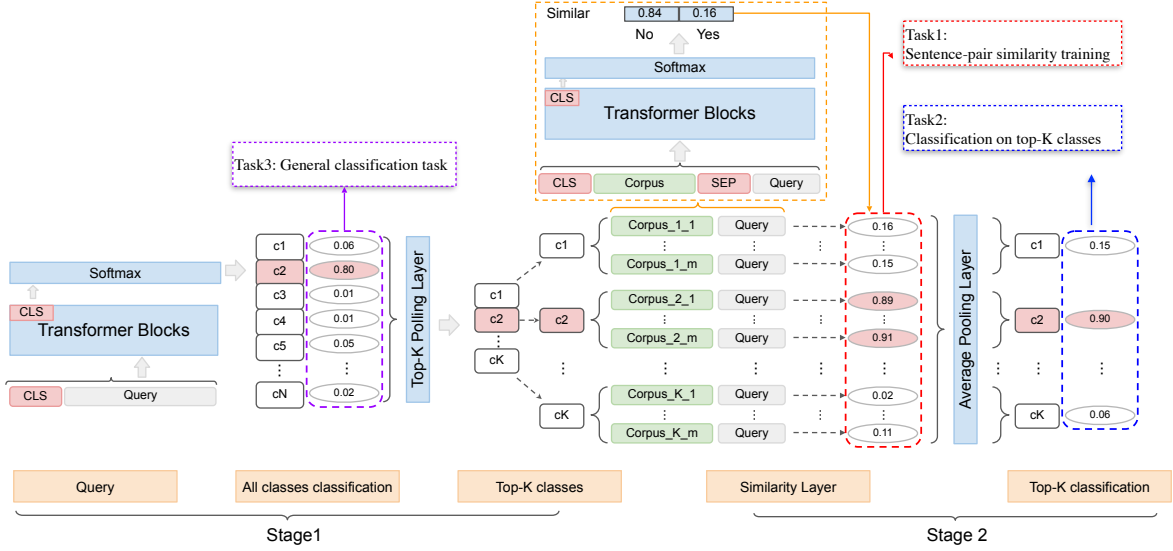


Figure 1: **Network Structure of SFC**: two-stage SFC and joint-SFC are sharing the same network from stage 1 and stage 2, with the only difference whether two stages being jointly trained.

parameters. Then, the loss in stage 1 classification model is shown in Equ. 1,

$$\mathcal{L}^C = \frac{1}{N} \sum_{i=1}^N -\log\left(\frac{\exp(\Phi_{i,y_i}^C)}{\sum_{j=1}^C \exp(\Phi_{i,j}^C)}\right) \quad (1)$$

### Stage 2: sentence-pair similarity model based classification with multi-task learning

We continue choosing RoBERTa as the main module in this stage that identifies the class label with strongest semantic similarity to the user input sentence.

Suppose we have a training dataset  $\mathcal{D} = \{x_i, y_i\}_{i=1}^N$  of  $N$  data points, in which  $x_i$  is the user input query and  $y_i$  is a single class label from a class label set of  $C$  classes in total. We generate a sentence pair dataset  $\mathcal{D}' = \{(x, x')_j, l_j\}_{j=1}^M$  from  $\mathcal{D}$ , where  $(x, x')_j$  is a pair of two history queries<sup>1</sup>, and  $l_j \in \{0, 1\}$  denotes the similarity label that only the ones from the same class label are considered similar. The size of  $\mathcal{D}'$  would be up to  $O(N^2)$  if no any sampling strategy is used. This is quite time-consuming for the training in stage 2 because  $N$  can be several hundreds or thousands even under few shot setting in task-specific chatbot scenario.

Therefore, we adopt the idea of adversarial negative sampling strategy from the work (Bamler and

Mandt, 2020). The key idea is to train with negative samples that are hard to be distinguished from positive samples. Now suppose we have a user input query  $x_i$  and top- $K$  most related class labels set  $\mathcal{C}' = \{c'_1, \dots, c'_K\}$  provided by auxiliary model or tool in stage 1, where  $K$  is a hyperparameter to control candidate class number, we apply the adversarial negative sampling strategy into our sentence pair sampling process by the following two steps:

The first step is *positive sentence pair sampling*. During the training process, we first make sure the ground truth class label  $y_i$  for  $x_i$  is within the candidate class label set  $\mathcal{C}'$ . If  $y_i \notin \mathcal{C}'$ , we manually add  $y_i$  into  $\mathcal{C}'$  by replacing  $c'_K$  with  $y_i$ , since  $c'_K$  is the least promising candidate label according to the auxiliary model in stage 1. Afterwards, we will randomly sample  $P$  sentences  $\{x'_1, \dots, x'_P\}$  with the same class label as  $y_i$  from dataset  $\mathcal{D}$  to form the set of sentence pairs with positive label  $\mathcal{P}'_i = \{[(x_i, x'_1), 1], \dots, [(x_i, x'_P), 1]\}$ , where  $P$  is also a hyperparameter set to control the number of sentences we should sample from each class.

The second step is *negative sentence pair sampling*: As for negative sentence pairs, we will also randomly sample  $P$  sentences for each class in the negative candidate class label set  $\mathcal{C}' \setminus \{y_i\}$ . The class labels in  $\mathcal{C}' \setminus \{y_i\}$  are the set of most confusing class labels comparing to the ground truth  $y_i$ , so we assume that the sentence pairs with negative label grouped by user input query  $x_i$  and sentences with class labels in  $\mathcal{C}' \setminus \{y_i\}$  are strong adversarial negative samples for sentence-pair sim-

<sup>1</sup>For simplicity, we use query to denote a user's question or a response.

| Dataset     | Domain                 | #Class | #Training Samples                   | #Samples/Class          | Settings      |
|-------------|------------------------|--------|-------------------------------------|-------------------------|---------------|
| ITG         | FAQ chatbot            | 228    | 3938 * 0.7                          | 12                      | 3-fold        |
| Amazon-670k | Product review         | 250    | 2658 * 0.7                          | 8                       | 3-fold        |
| HWU64       | intent detect          | 64     | [320, 640, 960, 1280, 1920, 3200]   | [5, 10, 15, 20, 30, 50] | data sampling |
| CLINC150    | intent detect          | 150    | [750, 1500, 2250, 3000, 4500, 7500] | [5, 10, 15, 20, 30, 50] | data sampling |
| BANKING77   | intent detect          | 77     | [385, 770, 1155, 1540, 2310, 3850]  | [5, 10, 15, 20, 30, 50] | data sampling |
| FRAMES      | intent detect with ner | 21     | [208, 408, 984]                     | [10, 20, 50]            | data sampling |
| ATIS        | intent detect with ner | 21     | [168, 303, 544]                     | [10, 20, 50]            | data sampling |

Table 1: Statistics for all datasets and few shot settings.

ilarity model that can help enhance the training speed and performance. According to the same method as positive sentence pair sampling, we can obtain the set of sentence pairs with negative label as  $\mathcal{N}'_i = \{[(x_i, x'_1), 0], \dots, [(x_i, x'_{P \cdot K}), 0]\}$

In this way, we generate the sentence pair dataset  $\mathcal{D}'$  for stage 2 based on the top-K class label set  $\mathcal{C}'$  provided by stage 1 as  $\mathcal{D}' = \{\mathcal{P}'_i \cup \mathcal{N}'_i\}_{i=1}^N$ , in which we have  $M = N \cdot K \cdot P$  data points of sentence pairs in total.

Before starting to fine-tune our sentence-pair model on task-specific dataset, we first fine-tune RoBERTa on Quora dataset (Iyer et al., 2017), which contains 404,290 potential duplicate question pairs, for transfer learning. This is also the merit of similarity based model, as labeled task-specific classification data is hard to acquire, yet general sentence pairs with similar semantics can be much easier to acquire.

### Multi-task based training

We continue to do multi-task training on sentence-pair dataset  $\mathcal{D}'$  sampled from the top-K candidate class labels provided by stage 1. In stage 2, we have two tasks tuning our system.

The first task is *regular sentence-pair similarity task*. For sentence pair semantic similarity task, given a data point  $(x, x')_i$  with similarity label  $l_i$  from data set  $\mathcal{D}' = \{[(x, x')_i, l_i]\}_{i=1}^M$ , Roberta takes the final hidden state  $h_i$  of the first token [CLS] as the representation for the sequence of packed sentence pair  $(x, x')_i$ . Let's suppose we have a linear layer as  $\Phi_i^S = W^S h_i + b^S$ , where  $W^S$  and  $b^S$  are trainable parameters, and the probability score for  $(x, x')_i$  can be calculated as  $p_i^S = \text{softmax}(\Phi_i^S)$ .

Due to the fact that sentence pairs within the same class is much fewer than that from different classes, the dataset  $\mathcal{D}'$  is quite imbalanced. Therefore, we will accommodate a weight variable  $w^S = [K - 1, 1]$  to the loss to eliminate the

bias brought by data imbalance, shown in Equ. 2.

$$\mathcal{L}^S = \frac{1}{M} \sum_{i=1}^M -w_{l_i}^S \cdot \log\left(\frac{\exp(\Phi_{i,l_i}^S)}{\sum_{j=0}^1 \exp(\Phi_{i,j}^S)}\right) \quad (2)$$

The second task is *classification on top-K classes*. As minimizing similarity loss is not our final goal in the intention classification, we bring back classification loss again. In this task, the network is based on sentence pair similarity modules. The only difference is that we add a task-specific average pooling layer, shown in Fig. 1 to accomplish the classification task based on sentence-pair model.

We already know that the size of  $\Phi^S$  in task 1 is  $M \times 2 = (N \cdot K \cdot P) \times 2$ , where  $N$  is the total number of data points in original training data  $\mathcal{D}$ ,  $K$  is a hyperparameter that controls the number of candidate class labels provided by stage 1, and  $P$  is also a hyperparameter that controls the number of sentences we should randomly sample from each candidate class labels. Now, for the average pooling layer, we first reshape  $\Phi^S$  into the size of  $N \times K \times P \times 2$ , and then split it into  $\Phi^{K,pos}$  and  $\Phi^{K,neg}$ , and both of them will have the size of  $N \times K \times P$ . In this way,  $\Phi^{K,pos}$  can represent the level of similarity for each sentence pair, and in the mean time,  $\Phi^{K,neg}$  can represent the level of dissimilarity for each sentence pair. Then, we can do average pooling for each candidate class among the top-K classes as shown in Equ. 3.

$$\xi_{i,j}^{K,pos} = \sum_{p=1}^P \Phi_{i,j,p}^{K,pos} \quad \xi_{i,j}^{K,neg} = \sum_{p=1}^P \Phi_{i,j,p}^{K,neg} \quad (3)$$

With the average pooling result  $\xi_{i,j}^{K,pos}$  and  $\xi_{i,j}^{K,neg}$ , we also generate a top-K class label  $l_i^K \in [1, \dots, K]$  for each  $\xi_i^{K,pos}$  and  $\xi_i^{K,neg}$ . The loss for



top-K classification task is shown in Equ. 4. In Equ. 5 and Equ. 6, the first term  $\xi_{i,l_i^K}^{K,pos}$  and  $\xi_{i,l_i^K}^{K,neg}$  encourage high level of similarity and low level of dissimilarity for prediction of the correct label  $l_i^K$  within the top-K candidate classes.

$$\mathcal{L}^K = \frac{1}{N} \sum_{i=1}^N (\mathcal{L}_i^{K,pos} - \mathcal{L}_i^{K,neg}) \quad (4)$$

where

$$\mathcal{L}_i^{K,pos} = -\log\left(\frac{\exp(\xi_{i,l_i^K}^{K,pos})}{\sum_{j=1}^K \exp(\xi_{i,j}^{K,pos})}\right) \quad (5)$$

$$\mathcal{L}_i^{K,neg} = -\log\left(\frac{\exp(\xi_{i,l_i^K}^{K,neg})}{\sum_{j=1}^K \exp(\xi_{i,j}^{K,neg})}\right) \quad (6)$$

Finally, the overall loss function for multi-task learning in stage 2 is shown in Equ. 7. The training objective of stage 2 is to minimize the weighted sum of task-specific losses. Here  $\alpha_S$  and  $\alpha_K$  are weights of task 1 and task 2 respectively.

$$\mathcal{L} = \alpha_S \mathcal{L}^S + \alpha_K \mathcal{L}^K \quad (7)$$

## 2.2 Joint SFC

In two-stage SFC, Stage 1 and stage 2 are separate that there is no deep interaction with each other during training. In this case, the performance of stage 1 may limit the potential of stage 2; meanwhile, stage 2 also cannot give training feedback back to stage 1 for fine-tuning. Therefore, to further improve the overall performance of SFC, we proposed a joint model structure, shown in Fig. 1.

In joint SFC, classification model is being placed in lower layer level to dynamically provide top-K candidate class labels for the sentence-pair similarity model placed in higher layer level through a top-K pooling layer. In this way, classification model and similarity model can be merged into one single joint-model for multi-task training with sentence pairs sampled from varying candidate class labels, thus avoiding the limitation brought by 2 separate stage structure.

There are 3 tasks in total during the training process of joint SFC, shown in Fig. 1, and the overall

loss is also the weighted sum of all the task-specific losses, shown in Equ. 8. Here,  $\alpha_S$ ,  $\alpha_K$  and  $\alpha_C$  represent the weights for task 1 sentence-pair similarity in Equ. 2, task 2 top-K classification in Equ. 4, and task 3 general single sentence classification respectively in Equ. 1.

$$\mathcal{L} = \alpha_S \mathcal{L}^S + \alpha_K \mathcal{L}^K + \alpha_C \mathcal{L}^C \quad (8)$$

## 3 Experiments

### 3.1 Datasets

Our experiments aim to study the short text classification in the low-resource environment popular in the task-specific conversational chatbot application. Hence we choose and configure set datasets to serve this study. Different from the datasets from other short text classification research, such as semantics classification with very limited semantics labels and relatively longer input, the datasets adopted in our experiments are typically having comparatively large number of class labels, ranging from several dozens to hundreds, and each class label is associated with a handful of labeled queries with each query being usually one sentence. Table 1 displays their statistics. All settings of four public datasets would be released to github soon.

1. *ITG*, is a proprietary FAQ dataset from real-world chatbot project, which is composed of question and answer pairs about online English teaching. It contains 3,938 sample questions for 228 class labels, and each class label corresponds to a unique answer.
2. *Amazon-670K*, is a customer product review dataset for text classification task from the extreme classification repository. The complete dataset contains 670,091 class labels, 285,176 training samples and 150,875 testing samples (Bhatia et al., 2016). As each sample may correspond to multiple class labels, we keep only the first one. We further filter out the class labels that each one is associated with only 5 to 15 samples, or reviews, to mimic the chatbot scenario. From them, we sample 250 class labels as well as their samples to form a subset with 2658 samples.
3. *HWU64*, is a intention detection dataset designed for home robot scenario (Liu et al., 2019b). It aims at the specific task of capturing the intention for different user requests

| Models                          | CLINC150      |               |               |               |               |               | BANKING77     |               |               |               |               |               | HWU64         |               |               |               |               |               | ITG           | Amazon-670k   |
|---------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|                                 | 5             | 10            | 15            | 20            | 30            | 50            | 5             | 10            | 15            | 20            | 30            | 50            | 5             | 10            | 15            | 20            | 30            | 50            | 3-fold        | 3-fold        |
| TextCNN (classification)        | 0.5318        | 0.6963        | 0.7609        | 0.8142        | 0.8526        | 0.8867        | 0.4408        | 0.6436        | 0.7366        | 0.7918        | 0.8228        | 0.8619        | 0.3112        | 0.4007        | 0.4823        | 0.5272        | 0.5782        | 0.6262        | 0.6624        | 0.4401        |
| LEAM (classification)           | 0.7514        | 0.8203        | 0.8612        | 0.8802        | 0.9010        | 0.9180        | 0.5422        | 0.7812        | 0.8129        | 0.8280        | 0.8610        | 0.8727        | 0.4545        | 0.5554        | 0.5936        | 0.6599        | 0.6855        | 0.7046        | 0.7086        | 0.6091        |
| BERT-large (classification)     | 0.8080        | 0.8904        | 0.9265        | 0.9334        | 0.9497        | 0.9595        | 0.5780        | 0.8004        | 0.8518        | 0.8827        | 0.8858        | 0.8982        | 0.4711        | 0.5963        | 0.6342        | 0.7010        | 0.7117        | 0.7424        | 0.7485        | 0.6658        |
| ALBERT-xxlarge (classification) | 0.8497        | 0.9008        | 0.9296        | 0.9297        | 0.9466        | 0.9578        | 0.5549        | 0.7981        | 0.8231        | 0.8530        | 0.8571        | 0.9096        | 0.4879        | 0.6116        | 0.6135        | 0.6996        | 0.7094        | 0.7376        | 0.7253        | 0.6893        |
| RoBERTa-base (classification)   | 0.8732        | 0.9254        | 0.9363        | 0.9482        | 0.9558        | 0.9637        | 0.7305        | 0.8654        | 0.8808        | 0.9080        | 0.9061        | 0.9293        | 0.5831        | 0.6790        | 0.7064        | 0.7100        | 0.7320        | 0.7472        | 0.7734        | 0.6708        |
| RoBERTa-large (classification)  | <b>0.8974</b> | <b>0.9372</b> | <b>0.9508</b> | <b>0.9584</b> | <b>0.9621</b> | <b>0.9733</b> | <b>0.7690</b> | <b>0.8728</b> | <b>0.8966</b> | <b>0.9099</b> | <b>0.9227</b> | <b>0.9313</b> | <b>0.6044</b> | <b>0.7002</b> | <b>0.7129</b> | <b>0.7436</b> | <b>0.7493</b> | <b>0.7678</b> | <b>0.7990</b> | <b>0.7156</b> |
| RoBERTa-large (similarity)      | 0.8266        | 0.8861        | 0.9023        | 0.9084        | 0.9090        | 0.9407        | 0.757         | 0.8476        | 0.8614        | 0.8743        | 0.8749        | 0.8980        | 0.5425        | 0.6164        | 0.6503        | 0.6729        | 0.6947        | 0.7231        | 0.7418        | 0.6362        |
| 2-stage SFC (task1)             | 0.8979        | 0.9457        | 0.9517        | 0.9591        | 0.9610        | 0.9664        | 0.7975        | 0.8818        | 0.8962        | 0.9109        | 0.9187        | 0.9198        | 0.6477        | 0.7055        | 0.7200        | 0.7232        | 0.7484        | 0.7653        | 0.7972        | 0.7189        |
| 2-stage SFC (task2)             | 0.9162        | 0.9424        | 0.9530        | 0.9617        | 0.9633        | 0.9690        | 0.7997        | 0.8823        | 0.8945        | 0.9123        | 0.9236        | 0.9317        | 0.6498        | 0.6980        | 0.7202        | 0.7358        | 0.7498        | 0.7657        | 0.8020        | 0.7311        |
| 2-stage SFC (task1 + task2)     | 0.9167        | 0.9456        | 0.9571        | 0.9638        | 0.9658        | 0.9753        | 0.8135        | 0.8854        | 0.8931        | 0.9192        | 0.9257        | 0.9339        | 0.6525        | 0.7092        | 0.7168        | 0.7476        | 0.7519        | 0.7696        | <b>0.8124</b> | 0.7364        |
| Joint SFC                       | <b>0.9231</b> | <b>0.9560</b> | <b>0.9644</b> | <b>0.9669</b> | <b>0.9712</b> | <b>0.9821</b> | <b>0.8270</b> | <b>0.9069</b> | <b>0.9103</b> | <b>0.9209</b> | <b>0.9323</b> | <b>0.9463</b> | <b>0.6697</b> | <b>0.7211</b> | <b>0.7254</b> | <b>0.7497</b> | <b>0.7593</b> | <b>0.7772</b> | 0.8114        | <b>0.7445</b> |

Table 2: F1 scores on five task-specific datasets for text classification in chatbot under low resource. For ITG, we keep the full dataset. For Amazon-670k, we randomly sampled 250 classes with training sample numbers within 5-15 samples per class. For CLINC150, BANKING77, HWU64, we set up various few-shot settings (5/10/15/20/30/50 samples per class) while keeping the test set to be fixed. The highest scores among all the baseline models and SFC variants for each data setting are both marked in bold.

to home robot and finding the corresponding answer. The raw dataset contains 25,716 data points for 64 class labels through crowdsourcing.

4. *CLINC150*, is a dataset designed for task-oriented systems with 23,700 queries that are short and unstructured for 150 intents, in the same style made by real users through crowdsourcing (Larson et al., 2019).
5. *BANKING77*, is a intention detection dataset for bank customer services. The raw dataset contains 13,084 data points for 77 class labels (Casanueva et al., 2020).
6. *FRAMES*, is a collection of multi-domain dialogues dealing with hotel bookings. The raw data is consists of 1369 human-human dialogues with slot filling information. There are 30,522 utterances in total for 21 intents and 49 slots (Asri et al., 2017).
7. *ATIS*, is a popular dataset for intent detection of flight reservations with slot filling (Tur et al., 2010). The raw data’s training, development and test sets contain 4,478, 500 and 893 utterances, respectively. There are 120 slot labels and 21 intent types for the training set.

Regarding the first two datasets, we conduct 3-fold cross validation experiments that 70 percent as training, 15 percent as validation and testing respectively, and report the averaged testing results. Regarding the last five datasets, we conduct experiments using a sampling method similar to that in

(Casanueva et al., 2020) yet in a more sophisticated few-shot settings. We fix a test data for each one, and examine their performances using 5, 10, 15, 20, 30, or 50 samples per class label respectively for training. This is important, as in practice, a task-specific chatbot usually starts with merely a handful of labeled data available in the early stage. Besides, in the active learning framework, building an effective auxiliary system with limited resource is also quite important to help developers label data more efficiently.

### 3.2 Baselines

We choose three kinds of system as our baselines. All our pretrained model baselines are fine-tuned on our datasets. Especially, the similarity model baseline and all similarity modules in SFCs use extra Quora dataset (Iyer et al., 2017) to enhance system performance.

1. *Pretrained model based classification system*, which consists of BERT (Devlin et al., 2018), RoBERTa (Liu et al., 2019c), and ALBERT (Lan et al., 2019) based. These pretrained models are practically proven to achieve outstanding performances in classification task and other NLP tasks.
2. *Non-pretrained model based classification system*, which consists of a typical CNN based TextCNN (Kim, 2014), and a label-embedding based LEAM (Wang et al., 2018). Regarding TextCNN, the model is based on output from RoBERTa tokenization, and the kernels are set as 1, 2, 3, 4, 5. Regarding LEAM, a literal

class label is required, which is available only in HWU64, CLINC150, BANKING77. Thus, for other two datasets, we have to use its class number instead. Empirically, a non-pretrained model based system are not performing as well as a pretrained models based, if both is applicable in some task. Our listing these non-pretrained model based systems here is to provide a comprehensive performance comparison on our datasets.

3. *Pre-trained model based similarity model.* We choose RoBERTa-large as our fundamental module as our SFC systems are based on RoBERTa too, and RoBERTa is empirically more effective than other pretrained models in the short text classification task in our experiments. In inference, we use an elastic search to find a set of potential candidate labels for the similarity model, to guarantee a reasonable running time.
4. *Pre-trained model based text classification and NER joint model.* Considering a joint model, our SFC framework is also supportive of NER task. That is in stage 1, based on the output states from a pretrained model, we can derive a fourth task for NER loss. For performance comparison, we choose the state-of-the-art model, which is RoBERTa-large with NER loss, using the same model structure with (Chen et al., 2019b), as our baseline.

Our SFC systems include two-stage SFC with ablation, trained with two tasks separately and both, and joint SFC with all three tasks. All setting details can be found in the appendix due to the space limitation.

### 3.3 Result Analysis

We report the F1 score <sup>2</sup> as the main evaluation measure for all experiments in Table 2 and Table 3.

#### Are multi-task and joint training working?

First, we compare the four SFC variants to analyze the improvement brought by multi-task and joint-model structure.

Comparing with training two-stage SFC with multi-task, training with only task 1, namely the sentence pair similarity model, degrades by 0.8

<sup>2</sup>In the multi-class and multi-label case, this is the average of the F1 score of each class with weighting depending on the numbers in each class.

| Models                                | FRAMES        |               |               | ATIS          |               |               |
|---------------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|
|                                       | 10            | 20            | 50            | 10            | 20            | 50            |
| RoBERTa-large (classification)        | 0.3456        | 0.4043        | 0.4262        | 0.9349        | 0.9757        | 0.9800        |
| RoBERTa-large (classification w/ NER) | 0.3520        | 0.4088        | 0.4353        | 0.9560        | 0.9706        | <b>0.9832</b> |
| Joint SFC (w/o NER)                   | 0.3843        | 0.4130        | 0.4390        | 0.9618        | 0.9761        | 0.9825        |
| Joint SFC (w/ NER)                    | <b>0.3925</b> | <b>0.4420</b> | <b>0.4456</b> | <b>0.9639</b> | <b>0.9784</b> | 0.9826        |

Table 3: F1 scores on two task-specific datasets for joint training of sentence classification and NER in chatbot domain under low resource. For both FRAMES and ATIS, we set up various few-shot settings(10/20/50 samples per intent) while keeping the original test set.

| F1 score       | Two-stage SFC | Joint SFC    | Gap   |
|----------------|---------------|--------------|-------|
| top-1 accuracy | <b>81.50</b>  | 81.07        | -0.47 |
| top-5 accuracy | 94.01         | <b>94.30</b> | +0.29 |

Table 4: The average classification accuracy in percent-age in stage 1 on all five dataset.

percent point on average, and training with only task 2, namely the top-K based classification task, degrades by 0.45 percent point on average. These degradation indicates multi-task training in two-stage SFC is helpful for the system performance. Besides, task 2 plays a relatively more important role in multi-task learning, and this aligns with their optimal weight settings.

Joint SFC consistently outperforms two-stage SFC with multi-task training on 5 diverse datasets by 0.95 percents on average. This observation supports the idea that the joint model structure can alleviate the limitation brought by the lack of interaction between two stages. In following analysis, we will focus on the comparison between joint SFC and the other baseline models.

#### Is the fusion of classification and similarity models helpful?

We compare joint SFC with classification, similarity and NER joint model based baselines respectively.

Regarding the classification models, joint SFC outperforms RoBERTa-large based, the strongest among all baselines, by 2.04 percent points on average F1 score over 5 datasets. Especially, ALBERT.xxlarge based is rather unstable in this scenario. Thus, we did multiple run with different settings and report the best ones here. Comparatively, RoBERTa based is the most stable and has the best performance in almost all experiment settings.

| Dataset     | Model         | $K = 3$<br>$P = 20$ | $K = 5$<br>$P = 10$ | $K = 10$<br>$P = 5$ | $K = 15$<br>$P = 4$ | $K = 20$<br>$P = 3$ |
|-------------|---------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| ITG         | two-stage SFC | 0.8034              | 0.8124              | 0.8008              | 0.7967              | 0.7934              |
|             | joint SFC     | 0.7986              | 0.8114              | 0.8010              | 0.7972              | 0.7918              |
| Amazon-670k | two-stage SFC | 0.7278              | 0.7364              | 0.7366              | 0.7328              | 0.7204              |
|             | joint SFC     | 0.7334              | 0.7445              | 0.7516              | 0.7344              | 0.7373              |

Table 5: We show the performances of SFC from different settings of hyperparameters,  $K$  denoting the candidate class number from stage 1,  $P$  denoting the number of sampled sentence pair in stage 2.

Regarding the similarity model, as analyzed above, we only choose the RoBERTa-large based implementation as our baseline. Joint SFC achieves more improvement of 7.09 percent points on average F1 score.

As for the intent classification and NER joint model, we choose the state-of-the-art RoBERTa-large model with NER loss as our strongest baseline. For ablation study, we did experiments on Joint SFC model with and without NER loss respectively. From Table 3, we can see that our Joint SFC without NER loss still outperforms RoBERTa with NER loss baseline by 0.86 percent points on average. This indicates that the fusion of classification and similarity can even works better than fusing with additional NER information under few-shot chatbot scenario. Moreover, after adding NER loss to Joint SFC, it achieves further improvement by 1.66 percent points over RoBERTa with NER loss baseline. Especially for FRAMES dataset, which is a much more difficult task in comparison with ATIS, our Joint SFC with NER loss achieves a bigger improvement of 2.8 percent points on average. In this way, we show the compatibility of our Joint SFC model with extra semantic information, as well as the stable outstanding performance of Joint SFC when facing hard tasks with few training data.

The above analysis illustrates that suitable fusing these two kinds of models can take their advantages.

### Does joint SFC improve the classification in stage 1?

We compare the top-1 prediction and top-5 candidate labels in stage 1 from two-stage SFC and joint SFC in Table 4. We should note that two-stage SFC does not optimize the stage 1 model, which is a RoBERTa based classification model.

The joint training does not improve the classification performance in stage 1, measured by top-1 accuracy. However, it improves the quality of top-5

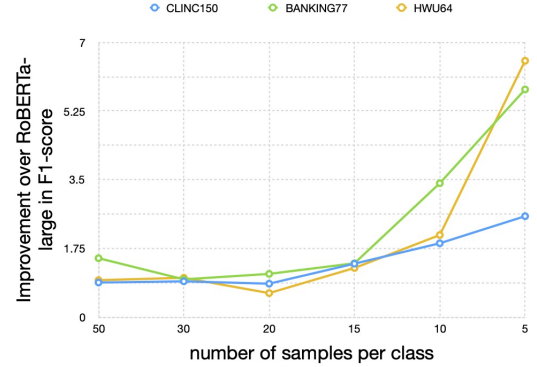


Figure 2: Improvements from Joint SFC over RoBERTa based classification with different size of training data.

candidate class labels, which can further improve the effect of sentence pair similarity training. The reason is that, a classification model inherently optimizes the objective loss, 0-1 error of top-1 here; the sentence pair similarity model in the joint SFC poses more positive effect in optimizing the candidate labels.

### How does training sample size influence SFC?

We analyze the overall improvement trend of joint SFC under various few-shot settings, and show results in Fig. 2.

Our main focus is to study chatbot building in common situation during real-world application where only a few sample sentences are available for each class. The experimental results for the 3 diverse intention detection datasets (CLINC150, BANKING77, HWU64) under few-shot settings, 5 to 50 samples per class, indicate that our proposed joint SFC can achieve 2.47 percents average improvement over one of the most powerful baseline models, which is RoBERTa-large classification model. Moreover, the improvement in F1 score becomes more and more prominent with the decrease of data sample number per class.

Especially, in the most extreme few-shot setting



with only 5 training samples per class our joint SFC achieves 4.97 percent points improvements on average over RoBERTa-large classification model. This observation indicates that SFC is especially well-performed when being applied during the initial stage of building task-specific chatbot system, where the amount of data sample for each class label is extremely scarce.

Furthermore, our proposed joint SFC can also achieve 2.04 percents average improvement over RoBERTa-large classification model on all the data settings including the ones with large scale, 30 to 50 samples per class. This indicates that joint SFC can still steadily outperforms pretrained model based baseline even if the data size grows bigger. However, the improvement is still more prominent when the data is scarce, which makes SFC an excellent model for low-resource chatbot scenario.

### How does joint SFC relate to the label embedding based LEAM?

LEAM performs consistently better than TextCNN by a large margin in all datasets. TextCNN is practically efficiently in task-specific chat applications, and LEAM shows its power in modeling labeling information.

LEAM does not perform as well as SFCs, since the first intuitive reason is it does not use pretrained model as encoding module; and another critical reason is in task-specific chat applications, it is common to have many intentions that are close to some others with a minor difference, and it is hard and even impossible to name each intention with a short clear name. One candidate solution is setting a most standard sample as the label of that class. When using non-pretrained models base LEAM, this is applicable. Yet when using pretrained model based, as the all labels can be hundreds of thousands, then this can not be accommodated in a poplar 32 G Tesla V100 GPU. Actually, joint SFC can be kind of understood as a generalization form of LEAM. In the scenario when there is no clear class label, the relationship between a sample and a class label is implicitly encoded as that between a sample and another sample from the same class, and this turns into a sentence pair similarity model.

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## A Appendix

### A.1 Related work

We supplement some work that is very different from classic classification models.

One line of work is based on label-word joint embedding, such as LEAM (Wang et al., 2018), MTLE (Zhang et al., 2017) and EXAM (Du et al., 2019). It poses extral requirements on label information. However in our case, many class labels are close to each other, and not well-defined. Though we can present the class label with one of user’s utterances from that class, the label will become not only prolix but also biased.

Another line of interesting work is the joint training of sentence classification and NER, such as (Kruengkrai et al., 2020; Zhang et al., 2020; Hakkani-Tür et al., 2016; Liu and Lane, 2016; Goo et al., 2018). For example, If both the city and date information are recognized, then they are good indicators that this query might be booking an ticket.

### A.2 Settings of hyperparameters

In Table 5, we explore the influence from hyperparameters, which are the number of candidate class labels  $K$  in stage 1, and the number of sampled sentence pairs for each class  $P$  in stage 2, on ITG and Amazon-670K datasets. As we control the total number of sampled sentence pairs to about 50 to 60, we roughly obatin five combinations of hyperparameters.

We find that the best setting of hyperparameters is different from datasets of different data size. The class label number of ITG and Amazon-670k are similar in our experimental setting, which is around 250. However the total amount of data points of ITG is approximately 2 times larger than Amazon-670k. Therefore, the setting of  $K = 5$  and  $P = 10$  is good enough for ITG since most of the classes contains over 10 data points. However, for Amazon-670k, the amount of data sample for each class is scarce, thus, we may need more candidate classes to sample enough effective sentence pairs for sentence-pair model layer of SFC. In this way, the setting of  $K = 10$  and  $P = 5$  becomes a good choice.

However, in spite of the effect on evaluation performance brought by different settings of hyperparameters, joint SFC still steadily outperforms two-stage SFC by 0.41 percent points in overall average F1 score on ITG and Amazon-670k datasets.

### A.3 Implementation Details

For our SFC systems, we use RoBERTa-large as the pretrained model for both classification task and sentence-pair similarity task. We fine-tune our SFC system on our datasets with max sequence length of 128, learning rate of  $1.5e-5$  for RoBERTa-large pretrained model and learning rate of  $5e-4$  for task-specific layer with polynomial decay and Adam optimizer.

In two-stage SFC, in equ. 7 the weights of two tasks are set as  $\alpha_S = 0.125$  and  $\alpha_K = 0.875$  in our setting. The reason for giving task 2 relatively more weights is that according to the ablation experiments we did in Section 3, task 2 contributes more to the overall performance. In joint SFC, in equ. 8, the weights of three tasks are set as  $\alpha_S = 0.25$ ,  $\alpha_K = 0.25$  and  $\alpha_C = 0.5$  in our setting. Overall, the task weights are less sensitive in Joint SFC than in two-stage SFC.

For the experiments in Table 2, we empirically set the hyperparameter to be  $K = 5$  and  $P = 10$  for all SFC variants. In Table 5, we conduct extensive experiments to see the performance of SFC system under various hyperparameter settings.

As for the training time, in our settings, our joint SFC model needs about 14 hours to reach convergence using a single Nvidia RTX8000 GPU. In comparison, the classification baseline model needs about 5 hours and the similarity baseline model needs about 12 hours, which indicates that our joint SFC model spends less training time than the summation of two baseline models due to faster convergence.

As for the inference time, the classification model baseline is about 0.2 ms; the similarity model baseline is about 0.5 ms and our joint SFC model takes only 0.6 ms. Actually both the similarity model baseline and our joint SFC can be GPU parallelized in the similarity computation, if we need pretty fast response time in a real product.