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

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Abstract

Task-specific chatbot systems have gained many important applications, such as smart speaker, customer service system. One fundamental module behind them is detecting intent of a user's input, and can be modeled as a short text classification problem. However, in the early stage of building a chatbot, collecting enough labeled data for hundreds of thousands of user intents is expensive. Popular classification models, direct mapping a query to an intent, have a high precision, while depending on enough task-specific labels information. In comparison, similarity models, modeling similarity of two queries instead, can utilize additional out-of-domain data, while having a relatively lower precision, due to the discrepancy of similarity loss and real classification loss. In this work, we propose a novel model, called similarity model fused with classification model (SFC), to combine the merits of the two kinds of models in the framework of multi-task training. Our extensive experiments on 6 public and 1 private datasets demonstrate that our systems outperform very strong baselines (i.e., RoBERTa based pretrained model, joint model with NER), especially with insufficient data.

1 Introduction

Task-specific conversational chatbot (Wen et al., 2016) has been applied into many practical products. A popular one is the smart speaker, e.g. Alex, Siri, Google home. Another important one is the customer service system, which greatly help human agents handle miscellanious customer's questions. No matter these applications involves single- or multi-round conversations, a critical step is to identify the intent behind a user's question or response. The detected intent with its associated attributes is then mapped into a predefined dialog logic to obtain a suitable response to return to customers.

In the early stage of building a chatbot , sufficient labeled data is often expensive to obtain to render the system to achieve a strong performance. People thus have to filter out enough typical users' utterances from tons of real conversation logs, and label them with proper intents. In practice, this procedure can be improved by active-learning like operations. A basic intent detection system with very limited manually labeled data can be built first, and then it filters out a set of potential data with high confidences for humans to label. The new data is added to train a better system again. This procedure iterates until the system reach a high performance. Therefore, it is meaningful to address the challenge of short-text classification (Sriram et al., 2010; Chen et al., 2019a; Phan et al., 2008; Yan et al., 2009; Hua et al., 2015) problem under the few-shot setting (Yu et al., 2018).

Existent approaches for intent detection can be roughly categorized as text classfication model and text similarity model.

The first one, *text classification model*, includes a variety of work. From traditional machine learning models like SVM (Suykens and Vandewalle, 1999), boosting tree (Tu, 2005), to neural networks (Wen et al., 2016), 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), and then to the most popular pretrained language models based, such as BERT (Devlin et al., 2018), RoBERTa (Liu et al., 2019c) and etc. Especiallaly, pretrained models based (Vaswani et al., 2017) tends to be more helpful in the few-shot scenario (Yu et al., 2018; Madabushi et al., 2020) to alleviate the dearth of training data. Another two interesting lines of work, label-word joint models, and joint NER and classification are discussed in the related work of appendix.

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 pretrained models to model the similarity calculation as a binary classification problem.

Despite plenty of success of these two methodologies, they still have some limitations in this task especially when data is insufficient. Regarding the *text classification model*, it learns a function that directly maps an input query into its expected label. Its training requires data in the form of a pair of a query and a task dependent label. 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 data augmentation methods to alleivate the paucity of data, e.g., translation based paraphrasing methods, the resulting benefit is still limited because of the data being homogeneous, in the case that our labeled data is very insufficient. Regarding the *similarity model*, the foremost advantage is it does not pose any restriction on the label definition of user intents, but aims to learn a function that measure how similar of two sentences are. Then in the intent detection task, we are only concerned which labeled query is the most similary one to the current input, and then use its label as the output. This results in a possibility that even though the labeled data in current domain is scarce, we may borrow additional data from another domain to help enhance the similarity model to make a better intent prediction. Nevertheless, just as every coin has two sides, the high flexibility of similarity model leads to its worse performance compared to a classification model, because its training loss differs from a classification loss corresponding to the intent detection goal. More, it requires an auxiliary model to narrow down candidate labeled queries to speed up the calculation, which makes it slow in the speed and tricky in the auxiliary model selection.

The above limitations motivate us to propose a system that may take both the high performance from 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. In order to train effectively, we further borrow the multi-task learning (Caruana, 1993; Collobert and Weston, 2008; Liu et al., 2019a). Our basic idea come naturally, and the first impementation 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 domain. In the second stage, we build a classification model which is composed of several similarity modules. Then, this structure derives two goals to train towards, the task-specific classification loss , and the similarity loss on both in-domain and out-of-domain data. In this version, the two stages are independently optimized, so we call it *2-stage SFC*.

We further find that the quality of outputs from the first stage might limit the final performance of the system, since those outputs are fixed in the whole system training procedure. This observation motivates us to continue improving the above 2-stage SFC into a joint training setting, and we call this second version as *joint-SFC*. In this way, the first stage model can be optimized by the optimization in the second stage so that it can provide better candidates to improve the performance of the second stage in turn.

Since SFC is in the framework of multi-task training, its inheriently supports adding additional tasks, such as NER, to gain further improvement.

2 Methodology

In this section, we describe our proposed SFC method, which includes a basic 2-stage SFC implementation and a more compact version called joint SFC.

2.1 2-stage SFC

We first introduce this most intuitive implementation. The outputs of the first stage are fed into the second stage, yet its parameters can not be tuned based on feedback of the second stage.

Stage 1: top-K candidate class labels generation

Any model that generates top-K most related class labels can be adopted in stage 1, such as classification models, term frequency-inverse document Frequency (TF-IDF) based retrieval models. Due to the excellent performance of RoBERTa in practice, we use RoBERTa to construct a classification model in this stage.

Suppose we have a training dataset $\mathcal{D} = \{x_i, y_i\}_{i=1}^{N}$, in which x_i is the user input query and y_i is a single class label in $\{1, \ldots, J\}$. Given x_i, we take the final hidden state h_i of the first

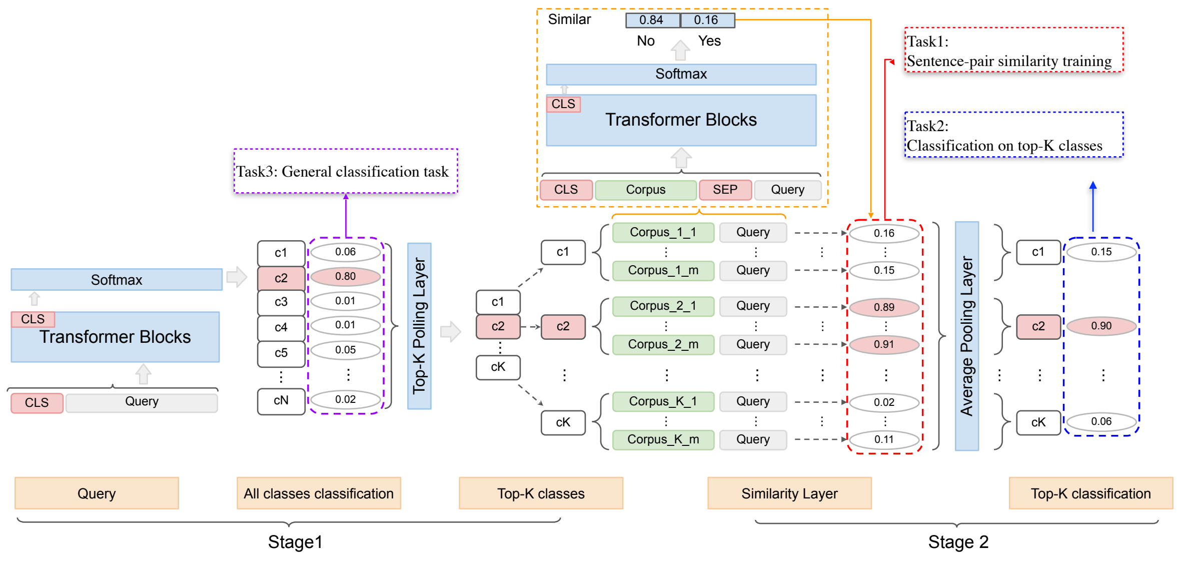

Figure 1: **Network Structure of SFC:** 2-stage SFC and joint-SFC are sharing the same network, with the only difference whether the two stages being jointly trained.

token [CLS] encoded by RoBERTa as the representation for the whole sequence of x_i. A linear layer is followed to output unnormalized probabilistic distribution of class labels, $\Phi_i^C = W^C h_i + b^C$, where W^C and b^C are class label related trainable parameters. Then, the loss in stage 1 classification model is shown in Equ. 1,

$$\mathcal{L}^C = \frac{1}{N}\sum_{i=1}^{N} -log(\frac{exp(\Phi^C_{i,y_i})}{\sum_{j=1}^{J} exp(\Phi^C_{i,j})}) \quad (1)$$

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

We continue choosing RoBERTa to construct main modules in this stage.

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 [1], and $l_j \in \{0, 1\}$ denotes the similarity that only the pair from the same class label is considered similar. The size of $\mathcal{D}'$ would be up to N^2 without a sampling strategy. This is prohibitively large and time-consuming for model training in stage 2, because N can be several hundreds or thousands even under few shot setting in our 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 label set $\mathcal{C}' = \{c'_1, \ldots, c'_K\}$ from stage 1, where K is a hyperparameter, we apply the adversarial negative sampling strategy into our sentence pair sampling in two steps:

The first step is *positive sentence pair sampling*. In training, we make sure the ground truth class label y_i of x_i exists in the candidate class label set $\mathcal{C}'$. Otherwise, we have it substitute for the least relevant class label c'_K. Then, we randomly sample P sentences $\{x'_1, \ldots, x'_P\}$ with the same class label as y_i from dataset $\mathcal{D}$ to form the set of sentence pairs with positive label $\mathcal{P}'_i = \{[(x_i, x'_1), 1], \ldots, [(x_i, x'_P), 1]\}$, where P is also a hyperparameter.

The second step is *negative sentence pair sampling*. We also randomly sample P sentences for each class in the negative candidate class label set $\mathcal{C}' \backslash \{y_i\}$, which is the more confusing to the expected class label compared to those out of top-K candidate set. The resulting sentence pairs are strong adversarial negative samples for sentence-pair similarity model, and they significantly enhance the training speed and performance. We denote them as $\mathcal{N}'_i = \{[(x_i, x'_1), 0], ..., [(x_i, x'_{P \cdot K}), 0]\}$

In this way, we generate the sentence pair dataset $\mathcal{D}'$ for stage 2, based on the top-K class label set $\mathcal{C}'$ from by stage 1, as $\mathcal{D}' = \{\mathcal{P}'_i \cup \mathcal{N}'_i\}_{i=1}^{N}$, and its size is $M = N \times K \times P$.

As analyzed before, one advantage of similarity based model is its potential to use out-of-domain

[1]For simplicity, we use query to denote a user's question or a response.

data. We take this advantage and use extra Quora dataset (Iyer et al., 2017) to enhance performance of both baseline and our SFCs.

Multi-task based training

We have our stage 2 model train on two tasks in the framework of multi-task training.

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 $\mathcal{D}'$, Roberta takes the concatenation of x, x' and outputs hidden state h_i of the first token [CLS] as its representation. A linear layer is followed as $\Phi_i^S = W^S h_i + b^S$ to generate unnormalized probabilities, where W^S and b^S are trainable parameters.

We note that the dataset $\mathcal{D}'$ is unbalanced, as negative samples are $K-1$ times as many as positive samples. Therefore, we add a weight $w^S \in \{K-1, 1\}$ to the loss of positive and negative samples respectively to eliminate the bias, shown in Equ. 2. This weighting strategy is quite effective in practice.

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

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

The size of Φ^S in task 1, namely unnormalized probabilistic distribution, is $2 \times M$, as one sentence pair correspond to two class labels. Further, it equals $(N \cdot K \cdot P) \times 2$, where N is the size of original training data $\mathcal{D}$, K the number of candidate class labels from stage 1, and P is the number of sentences randomly sampled from each candidate class label. Now, for the average pooling layer, we first reshape Φ^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, $\Phi^{K,pos}$ represents the level of similarity for each sentence pair, and $\Phi^{K,neg}$ represents 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.

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

With the average pooling result $\xi^{K,pos}$ and $\xi^{K,neg}$, we also generate a top-K class label $l_i^K \in [1, \ldots, K]$ 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

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

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

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 α_S and α_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 2-stage SFC, two stages are separate that there is no deep interaction with each other during training. In this case, the performance of stage 1 may limit the model potential in stage 2; meanwhile, stage 2 also cannot loop feedback back to stage 1 in trainig for improvement. Therefore, we propose to jointly train all stages, shown in Fig. 1.

In joint SFC, a classification model is placed in stage 1 to dynamically provide top-K candidate class labels for the sentence-pair similarity model in stage 2 through a top-K pooling layer. In this way, classification model and similarity model can be merged into one single model for multi-task

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)	**0.8974**	**0.9372**	**0.9508**	**0.9584**	**0.9621**	**0.9733**	**0.7690**	**0.8728**	**0.8966**	**0.9099**	**0.9227**	**0.9313**	**0.6044**	**0.7002**	**0.7129**	**0.7436**	**0.7493**	**0.7678**	**0.7990**	**0.7156**
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	**0.8124**	0.7364
Joint SFC	**0.9231**	**0.9560**	**0.9644**	**0.9669**	**0.9712**	**0.9821**	**0.8270**	**0.9069**	**0.9103**	**0.9209**	**0.9323**	**0.9463**	**0.6697**	**0.7211**	**0.7254**	**0.7497**	**0.7593**	**0.7772**	0.8114	**0.7445**

Table 1: 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.

training with sentence pairs sampled from varying candidate class labels.

There are 3 tasks in total during the training of joint SFC, shown in Fig. 1. The overall loss is a linear combination of them, shown in Equ. 8. Here, α_S, α_K and α_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.

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

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. The datasets adopted in our experiments, showed in Table 2 [2], typically contain 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.

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.

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 only associated to training samples within the amount of 5 to 15 to mimic the few-shot chatbot scenario. From them, we sample 250 class labels as well as their training samples to form a subset with 2658 samples.

HWU64, is an intent detection dataset designed for home robot scenario (Liu et al., 2019b). It aims at the specific task of capturing the intent for different user requests to home robot and finding the corresponding answer. The raw dataset contains 25,716 data points for 64 class labels through crowdsourcing.

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).

BANKING77, is an intent detection dataset for bank customer services. The raw dataset contains 13,084 data points for 77 class labels (Casanueva et al., 2020).

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).

ATIS, is a popular dataset for intent detection of flight reservations with slot filling(Tur et al., 2010).

[2] All settings of six public datasets would be released to github soon.

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 detection	64	[320, 640, 960, 1280, 1920, 3200]	[5, 10, 15, 20, 30, 50]	data sampling
CLINC150	Intent detection	150	[750, 1500, 2250, 3000, 4500, 7500]	[5, 10, 15, 20, 30, 50]	data sampling
BANKING77	Intent detection	77	[385, 770, 1155, 1540, 2310, 3850]	[5, 10, 15, 20, 30, 50]	data sampling
FRAMES	Intent detection with NER	21	[208, 408, 984]	[10, 20, 50]	data sampling
ATIS	Intent detection with NER	21	[168, 303, 544]	[10, 20, 50]	data sampling

Table 2: Statistics for all datasets and few shot settings.

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 treat 70 percent as training, 15 percent as validation and testing respectively, and report the averaged testing results. Regarding the last five datasets, we use a sampling method similar to that from (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 new data more efficiently.

3.2 Baselines

Our baselines comprise of *four* styles of systems.

The first one, *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 input is 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 in many NLP tasks. Our listing these non-pretrained model based systems here is serving a comprehensive performance comparison on our datasets.

The second one, *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.

The third one, *pretrained model based similarity model*. As RoBERTa is empirically found more effective than other pretrained models in the short text classification task in our experiments, we choose RoBERTa-large based implementation. 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.

The fouth one, *pretrained model based joint text classification and NER model*. We choose the work from (Chen et al., 2019b) as our baseline system, which utilizes a strong RoBERTa-large model to jointly train two losses. Our SFC framework is also conveniently supportive of extra NER loss that in stage 1 a fourth task with a NER loss is trivially derived based on the output states from a pretrained model.

All pretrained model baselines are fine-tuned on our datasets. Especially, the similarity model baseline and all similarity layers in SFCs use extra Quora dataset (Iyer et al., 2017) [3] to enhance system performance. This is also one of merits in SFC, as it support adopting out-of-domain data in comparison to a classification based model.

Our SFC implementations include three 2-stage SFCs using task 1 and 2 with ablation in Table 1; one joint SFC trained on all three tasks in Table 1; one joint SFC with an additional fourth NER task in Table 3.

All setting details can be found in the appendix due to the space limitation.

3.3 Result Analysis

We report the F1 score [4] as the main evaluation measure for all experiments in Table 1 and Table 3.

[3]which contains 404,290 potential duplicate question pairs

[4]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	**0.9832**
Joint SFC (w/o NER)	0.3843	0.4130	0.4390	0.9618	0.9761	0.9825
Joint SFC (w/ NER)	**0.3925**	**0.4420**	**0.4456**	**0.9639**	**0.9784**	0.9826

Table 3: F1 scores for joint sentence classification and NER training. We iterate various sample number per intent and test on original test set.

F1 score	2-stage SFC	joint SFC	Gap
top-1 accuracy	**81.50**	81.07	-0.47
top-5 accuracy	94.01	**94.30**	+0.29

Table 4: The average classification accuracy in percentage in stage 1 on all five dataset.

Multi-task and joint training

Comparing with training 2-stage SFC with multi-task Table 1, training with only task 1, namely the sentence pair similarity model, degrades by 0.8 percentage point on average, and training with only task 2, namely the top-K based classification task, degrades by 0.45 percentage point on average. These degradation indicates multi-task training in 2-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 2-stage SFC with multi-task training on 5 diverse datasets by 0.95 percentage point on average. Though a joint model structure may bring extra complexity to the system, it does alleviate the error propagation from the first stage and improves the final performance.

In following analysis, we will focus on the comparison between joint SFC and the other baseline models.

Dataset	Model	$K = 3$ $P = 20$	$K = 5$ $P = 10$	$K = 10$ $P = 5$	$K = 15$ $P = 4$	$K = 20$ $P = 3$
ITG	2-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	2-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: 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.

Fusion of classification and similarity models

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

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 percentage points on average F1 score. This is also understandable, since RoBERTa-large based similarity model does not and also can not train towards the task specific goal.

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

Joint SFC improves stage 1?

We explore the quality of predicted candidate labels in stage 1 from 2-stage SFC and joint SFC respectively. We should note that 2-stage SFC does not optimize the stage 1 model, namely a RoBERTa based classification model.

From Table 4, the joint training does not improve the top-1 classification accuracy in stage 1, yet it improves the top-5 accuracy. 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 joint SFC poses more positive effect in optimizing the candidate labels.

Supportive of extra NER task

Many previous work shows joint training with a NER loss improves the intent classification task as well, observed again in our baselines and SFCs in Table 3. We choose the state-of-the-art RoBERTa-large model with NER loss as a strong baseline.

We can see that our joint SFC without NER loss still outperforms RoBERTa with NER loss baseline by 0.86 percentage points on average. This indicates that the fusion of classification and similarity models can even works better than fusing with additional NER information under few-shot chatbot scenario.

Moreover, the adding NER loss to joint SFC further achieves improvement of 1.66 percentage

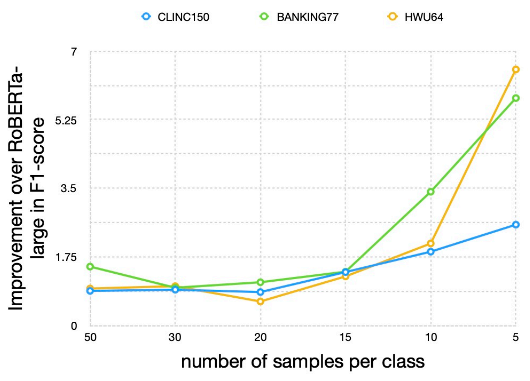

Figure 2: Improvements from joint SFC over RoBERTa based classification with different training size.

points over RoBERTa with NER loss baseline. Especially on FRAMES dataset, which is a much more difficult task in comparison with ATIS based on performance of all systems on it, our joint SFC with NER loss achieves a bigger improvement of 2.8 percentage points on average.

Different training sample size

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

Our main focus is on studying chatbot construction in real world applications, where each class has only a small number of example sentences. The experimental results for the 3 diverse intent detection datasets (ClINC150, BANKING77, HWU64) under few-shot settings, 5 to 50 samples per class, indicate that our proposed joint SFC can achieve average 2.47 percentage points 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 setting with only 5 training samples per class, joint SFC achieves 4.97 percentage points improvements on average over RoBERTa-large classification model. Joint SFC is a better choice applied into the early stage of building a task-specific chatbot system, since label data is extremely scarce.

Furthermore, joint SFC also achieves average 2.04 percentage points improvement over RoBERTa-large classification model on all the data settings. However, the improvement is still more prominent when the data is scarce, which makes SFC an excellent model for low-resource chatbot scenario.

3.4 Settings of hyperparameters

In Table 5, we explore the influence from hyperparameters on ITG and Amazon-670K datasets. We control the total number of sampled sentence pairs to about 50 to 60, and obatin about five combinations of hyperparameters.

We find that the best setting of hyperparameters is different with different datasets. The class label number of ITG and Amazon-670k are similar in our experiments, around 250. However the number of data points in ITG is approximately 2 times as many as that in 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, in Amazon-670k, the data per each class is scarce, and, we may need more candidate classes to sample enough effective sentence pairs for the stage 2 traininig of SFC. Thus, the setting of $K = 10$ and $P = 5$ becomes a good choice.

However, despite 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.

For the experiments in Table 1, we empirically set the hyperparameter to be $K = 5$ and $P = 10$ for all SFC variants.

3.5 Other settings

We fine-tune all SFC systems with the maximum sequence length of 128, learning rate of 1.5e-5 for RoBERTa-large pretrained model and 5e-4 for task-specific layer with a linear decay, and use 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. In joint SFC, in equ. 8, the weights of three tasks are set as $\alpha_S = 0.25$, $\alpha_K = 0.25$ and $\alpha_C = 0.5$. Overall, the task weights are less sensitive in joint SFC than in two-stage SFC.

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.

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