Boundary-Driven Table-Filling for Aspect Sentiment Triplet Extraction

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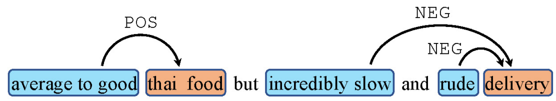
Abstract

Aspect Sentiment Triplet Extraction (ASTE) aims to extract the aspect terms along with the corresponding opinion terms and the expressed sentiments in the review, which is an important task in sentiment analysis. Previous research efforts generally address the ASTE task in an end-to-end fashion through the table-filling formalization, in which the triplets are represented by a two-dimensional (2D) table of word-pair relations. Under this formalization, a term-level relation is decomposed into multiple independent word-level relations, which leads to relation inconsistency and boundary insensitivity in the face of multi-word aspect terms and opinion terms. To overcome these issues, we propose Boundary-Driven Table-Filling (BDTF), which represents each triplet as a relation region in the 2D table and transforms the ASTE task into detection and classification of relation regions. We also notice that the quality of the table representation greatly affects the performance of BDTF. Therefore, we develop an effective relation representation learning approach to learn the table representation, which can fully exploit both word-to-word interactions and relation-to-relation interactions. Experiments on several public benchmarks show that the proposed approach achieves state-of-the-art performances[1].

Sentence:



The results of Aspect Sentiment Triplet Extraction:

{(thai food, average to good, POS),
(delivery, incredibly slow, NEG),
(delivery, rude, NEG)}

Figure 1: An example of the ASTE task. The aspect terms and the opinion terms are marked with orange and blue, respectively.

1 Introduction

As a fine-grained task, Aspect-Based Sentiment Analysis (ABSA) focuses on the attitudes expressed on specific aspect terms (Pontiki et al., 2014). Opinion terms refer to words or phrases expressing subjective sentiments. Intuitively, opinion terms are important clues when determining the sentiment polarity and could provide a more detailed sentiment description for the aspect terms. Previous work has generally concentrated on extracting aspect terms and opinion terms and classifying the sentiment expressed on the aspect term without explicitly considering the relations between aspect terms and opinion terms (He et al., 2019; Li et al., 2019; Chen and Qian, 2020). Therefore, Peng et al. (2020) propose the Aspect Sentiment Triplet Extraction (ASTE) task, which is exemplified in Figure 1. In the ASTE task, a triplet consists of an aspect term, the corresponding opinion term, and the expressed sentiment.

Peng et al. (2020) adopt the pipeline approach to address the ASTE task. They first decompose the ASTE task into several subtasks and then learn models separately for each subtask. A more advanced alternative is learning a joint model to exploit the interactions between different subtasks (Xu et al., 2020; Wu et al., 2020; Chen et al., 2021a; Mao et al., 2021; Xu et al., 2021; Jing et al., 2021). Among these works, Wu et al. (2020) and Jing

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[1] We make our code publicly available at `https://github.com/HITSZ-HLT/BDTF-ABSA`.

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et al. (2021) tackle the ASTE task through a table-filling approach, where the triplets are represented by a two-dimensional (2D) table of word-pair relations. In this approach, aspect terms and opinion terms are extracted through the diagonal elements of the table, and sentiments are treated as relation tags that are represented by the non-diagonal elements of the table. This formalization enables joint learning of different subtasks in ASTE, achieving superior performance over the pipeline approach.

However, the previous table formalization suffers from *relation inconsistency* and *boundary insensitivity* when dealing with multi-word aspect terms and opinion terms. It decomposes the relation between an aspect term and an opinion term into the relations between the corresponding aspect words and opinion words. In other words, a term-level relation is represented by several word-level relation tags. The relation tags in the table are assigned independently, which leads to potential inconsistencies in the predictions of the word-level relations. In addition, when there are minor boundary errors in the aspect term or opinion term, the voting result for the term-level relation may stay unchanged, encouraging the model to produce wrong predictions. Xu et al. (2021) try to solve this problem through a span-based method, but their method discards fine-grained word-level information, which is the advantage of the table-filling approach.

In this paper, we propose a Boundary-Driven Table-Filling (BDTF) approach for ASTE to overcome the above issues. Instead of decomposing ASTE into term extraction and relation classification, it extracts triplets by directly detecting and classifying the relation regions in a 2D table. Specifically, we first detect all possible relation regions in the table through a region detection layer, which is enabled by predefined boundary tags. Then we employ a region classifier to determine the sentiment label for each relation region. Classification over the entire relation region ensures relation consistency, and those relation regions with boundary errors can be removed by being classified as invalid.

To support the proposed BDTF, we also develop an effective relation representation learning approach to learn the table representation. We first learn the word-level contextualized representations of the input review through a pre-trained language model. Then we adopt a tensor-based operation to construct the relation-level representations to fully exploit the word-to-word interactions. Finally, we model relation-to-relation interactions through a multi-layer convolution-based encoder to enhance the relation-level representations. The relation representations of each two words in the review together form a 2D relation matrix, which serves as the table representation for BDTF.

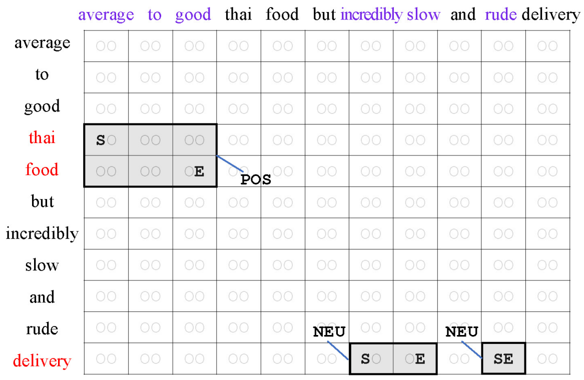

Figure 2: An example with BDTF for the ASTE task.

Our contributions can be summarized as follows:

- We propose a Boundary-Driven Table-Filling (BDTF) approach for the ASTE task. It extracts aspect sentiment triplets from reviews by directly detecting and classifying the relation regions, overcoming relation inconsistency and boundary insensitivity of the previous methods.
- We develop an effective relation representation learning approach to learn the table representation, which fully exploits both word-to-word interactions and relation-to-relation interactions.
- Extensive experiments are conducted on several aspect-opinion tasks including ASTE, and the results demonstrate that our approach significantly outperforms the state-of-the-art methods.

2 Our Approach

2.1 Task Formalization

Given a sentence $X = [x_1, x_2, \cdots, x_n]$ of length n, the goal of the ASTE task is to extract a set of aspect sentiment triplets. A triplet is defined as $(aspect, opinion, sentiment)$ where $sentiment \in \{\texttt{POS}, \texttt{NEU}, \texttt{NEG}\}$. As shown in Figure 2, we represent a triplet as a relation region in the 2D table. Its boundary is used to indicate

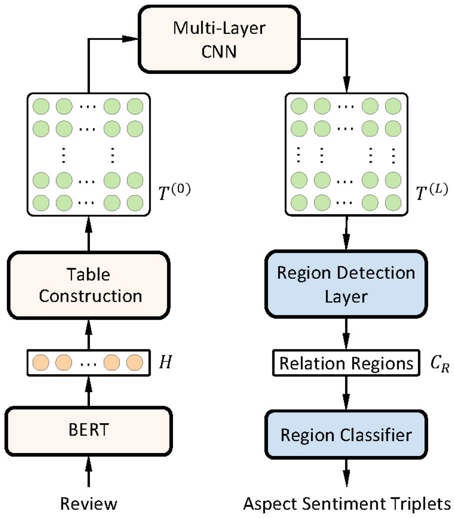

Figure 3: The proposed BDTF-ASTE approach.

the position of the aspect term and opinion term, and its type is used to indicate the sentiment. Relation regions are located by two boundary tags. Specifically, `S` denotes the upper left corner , and `E` denotes the lower right corner .

2.2 Model Overview

We briefly present the proposed approach in Figure 3. For an input review, we first learn the word-level contextualized representations via BERT and then learn a 2D table representation by constructing and encoding relation-level representations. Each element of this table representation is a vector representing a word-pair relation. Next, we detect all candidate relation regions in the table and predict the type of each relation region by a region classifier. Finally, we decode the aspect sentiment triplets based on the boundaries and types of the relation regions.

2.3 Representation Learning

2.3.1 Word-Level Representation Learning

We first employ a pre-trained language model such as BERT (Devlin et al., 2019) as the language encoder to obtain the word-level contextualized representations of the input sentence. This process can be formulated as follows:

$$\boldsymbol{h}_1, \boldsymbol{h}_2, \cdots, \boldsymbol{h}_T = \mathrm{BERT}(x_1, x_2, \cdots, x_T). \quad (1)$$

2.3.2 Relation-Level Representation Construction

Most of the existing work constructs the relation representation between two words by feature concatenation (Wu et al., 2020; Jing et al., 2021; Xu et al., 2021). However, this method *underutilizes* word-to-word interactions because a relation is not a simple composition of two words. Inspired by Socher et al. (2013), we adopt a tensor-based operation to construct the relation-level representation. Given two words $\boldsymbol{h}_i, \boldsymbol{h}_j \in \mathbb{R}^d$, the tensor-based operation is defined as:

$$\mathcal{T}(\boldsymbol{h}_i, \boldsymbol{h}_j; V) = \boldsymbol{h}_i^\top V^{[1:t]} \boldsymbol{h}_j, \quad (2)$$

where $V \in \mathbb{R}^{d \times d \times t}$ is a tensor parameter. Specifically, for each slice $V^{[k]} \in \mathbb{R}^{d \times d}$, the tensor-based operation computes the inner product of two word representations in a certain vector space:

$$\mathcal{T}(\boldsymbol{h}_i, \boldsymbol{h}_j; V)_k = \boldsymbol{h}_i^\top V^{[k]} \boldsymbol{h}_j. \quad (3)$$

By introducing multiple vector spaces, the tensor-based operation can fully model word-to-word interactions.

In addition, we also exploit the context between two words, as the context often contain important indicators of the expressed relation (Eberts and Ulges, 2020). We obtain the context representation $\boldsymbol{c}_{ij} \in \mathbb{R}^d$ by the max-pooling operation (let $i \leq j$):

$$\boldsymbol{c}_{ij} = \mathrm{pooling}(\boldsymbol{h}_i, \boldsymbol{h}_{i+1}, \cdots, \boldsymbol{h}_j). \quad (4)$$

Finally, we construct the relation-level representation $\boldsymbol{r}_{ij}^{(0)} \in \mathbb{R}^d$ through a nonlinear projection:

$$\boldsymbol{r}_{ij}^{(0)} = f(\mathrm{Linear}([\boldsymbol{h}_i; \boldsymbol{h}_j; \boldsymbol{c}_{ij}; \boldsymbol{t}_{ij}])), \quad (5)$$

$$\boldsymbol{t}_{ij} = \mathcal{T}(\boldsymbol{h}_i, \boldsymbol{h}_j; V) \in \mathbb{R}^t. \quad (6)$$

where $f(\cdot)$ is an activation function, and we empirically choose `gelu` (Hendrycks and Gimpel, 2016) in this paper.

2.3.3 Relation-Level Representation Encoding

The relation representations of each two words in the sentence together form a 2D relation matrix, *i.e.*, the table representation. There are some potential dependencies among the elements of this table representation. For example, an element with boundary tag `S` always has an element with boundary tag `E` at its lower right, and elements in the same relation region have the same sentiment label.

To model these dependencies, we utilize the ResNet-style CNNs (He et al., 2016) to encode this relation matrix. Specifically, given the input table representation $T^{(l-1)} \in \mathbb{R}^{n \times n \times d}$, the l-th layer CNN produces a table representation $T^{(l)}$ of the same size by:

$$T' = \mathrm{ReLU}(\mathrm{LN}(\mathrm{Conv}_{1\times1}(T^{(l-1)}))), \tag{7}$$
$$T'' = \mathrm{ReLU}(\mathrm{LN}(\mathrm{Conv}_{3\times3}(T'))), \tag{8}$$
$$T''' = \mathrm{ReLU}(\mathrm{LN}(\mathrm{Conv}_{1\times1}(T''))), \tag{9}$$
$$T^{(l)} = T''' + T^{(l-1)}, \tag{10}$$

where LN denotes Layer Normalization (Ba et al., 2016).

2.4 Extraction Module

2.4.1 Region Detection Layer

For each element $\boldsymbol{r}_{ij}^{(L)}$ in the table representation $T^{(L)}$, the region detection layer utilizes two classifiers to calculate the probability of its boundary tag being S and E:

$$P_{ij}^{\mathtt{S}} = \mathrm{sigmoid}\left(\mathrm{Linear}\left(\boldsymbol{r}_{ij}^{(L)}\right)\right), \tag{11}$$
$$P_{ij}^{\mathtt{E}} = \mathrm{sigmoid}\left(\mathrm{Linear}\left(\boldsymbol{r}_{ij}^{(L)}\right)\right). \tag{12}$$

Instead of decoding S and E based on a certain threshold, we prune S and E through a top-k strategy and then combine them to get the candidate relation regions. Pruning allows the model to avoid potential exposure bias[2] (Schmidt, 2019). Specifically, we select the top-k candidates by $P_{ij}^{\mathtt{S}}$ and $P_{ij}^{\mathtt{E}}$, respectively. Then these valid S-E pairs of the selected candidates form the region candidate pool $C_R = \{\cdots, [\mathtt{S}(a,b), \mathtt{E}(c,d)], \cdots\}$, where an S-E pair is only valid if E is not on top or left of S, (*i.e.*, $a \leq c$ and $b \leq d$). The value of k is related to the length of the input sentence:

$$k = \max(n \cdot z, k_{min}), \tag{13}$$

where z and k_{min} are two hyper-parameters.

2.4.2 Region Classifier

Given a candidate relation region determined by $\mathtt{S}(a,b)$ and $\mathtt{E}(c,d)$, we concatenate the S representation, the E representation, and the max-pooling result of the relation matrix over this region as its feature representation $\boldsymbol{r}_{abcd} \in \mathbb{R}^{3d}$:

$$\boldsymbol{p}_{abcd}^{(L)} = \mathrm{pooling}\begin{pmatrix} \boldsymbol{r}_{ab}^{(L)} & \cdots & \boldsymbol{r}_{ad}^{(L)} \\ \vdots & \ddots & \vdots \\ \boldsymbol{r}_{cb}^{(L)} & \cdots & \boldsymbol{r}_{cd}^{(L)} \end{pmatrix}, \tag{14}$$
$$\boldsymbol{r}_{abcd} = \left[\boldsymbol{r}_{ab}^{(L)}; \boldsymbol{r}_{cd}^{(L)}; \boldsymbol{p}_{abcd}^{(L)}\right]. \tag{15}$$

Then we use a classifier to predict its type $y_{\mathcal{T}} \in \{\mathtt{POS}, \mathtt{NEU}, \mathtt{NEG}, \mathtt{Invalid}\}$:

$$P_{abcd}(y_{\mathcal{T}}) = \mathrm{softmax}(\mathrm{Linear}(\boldsymbol{r}_{abcd})). \tag{16}$$

2.5 Training and Decoding

During training, we utilize the cross-entropy function to calculate the loss of boundary detection and region classification. Specifically, given the ground truth boundary label $y_{ij}^{\mathtt{S}}, y_{ij}^{\mathtt{E}} \in \{0,1\}$, the loss of region detection is calculated by:

$$\mathcal{L}_{\mathcal{B}} = \mathcal{L}_{\mathtt{S}} + \mathcal{L}_{\mathtt{E}}, \tag{17}$$
$$\mathcal{L}_{\mathtt{S}} = -\sum_{i,j\in[1,n]} y_{ij}^{\mathtt{S}} \log P_{ij}^{\mathtt{S}} + (1 - y_{ij}^{\mathtt{S}}) \log(1 - P_{ij}^{\mathtt{S}}),$$
$$\mathcal{L}_{\mathtt{E}} = -\sum_{i,j\in[1,n]} y_{ij}^{\mathtt{E}} \log P_{ij}^{\mathtt{E}} + (1 - y_{ij}^{\mathtt{E}}) \log(1 - P_{ij}^{\mathtt{E}}).$$

Given the ground truth region type $y_{\mathcal{T}}^*$, the loss of region classification is calculated by:

$$\mathcal{L}_{\mathcal{T}} = -\sum_{abcd\in C_R} \log P_{abcd}(y_{\mathcal{T}}^*). \tag{18}$$

The overall optimization objective is to minimize the summation of these two losses $\mathcal{L}_{\mathcal{B}} + \mathcal{L}_{\mathcal{T}}$.

During decoding, we first obtain the region candidate pool through the region detection layer and then utilize the region classifier to predict the type of each candidate region. We drop those relation regions whose predicted types are Invalid and generate the aspect sentiment triplets from the remaining relation regions. Suppose a relation region determined by $\mathtt{S}(a,b)$ and $\mathtt{E}(c,d)$ is predicted to be of type POS, then its corresponding triplet is:

$$aspect = [x_a, \cdots, x_c], \tag{19}$$
$$opinion = [x_b, \cdots, x_d], \tag{20}$$
$$sentiment = \mathtt{POS}. \tag{21}$$

3 Experiments

3.1 Datasets

We evaluate our approach on four public datasets from SemEval 2014[3] (Pontiki et al., 2014), SemEval 2015[4] (Pontiki et al., 2015), and SemEval 2016[5] (Pontiki et al., 2016). For these datasets, Fan et al. (2019) annotate opinion terms for each

[2] *Exposure bias* here means that for subsequent region classification, the true S and E are used during training, and the predicted S and E are used during inference, which will introduce discrepancies in the distribution.

[3] http://alt.qcri.org/semeval2014/task4/
[4] http://alt.qcri.org/semeval2015/task12/
[5] http://alt.qcri.org/semeval2016/task5/

Dataset	Split	#Sent	#A	#O	#T
Rest 14	Train	1266	2051	2061	2338
	Dev	310	500	497	577
	Test	492	848	844	994
Lap 14	Train	906	1280	1254	1460
	Dev	219	295	302	346
	Test	328	463	466	543
Rest 15	Train	605	862	935	1013
	Dev	148	213	236	249
	Test	322	432	460	485
Rest 16	Train	857	1198	1300	1394
	Dev	210	296	319	339
	Test	326	452	474	514

Table 1: Statistics of ASET-Data-v2 (Xu et al., 2020). #Sent, #A, #O, and #T represent the number of sentences, aspect terms, opinion terms, and triplets, respectively.

aspect term. Based on this, Peng et al. (2020) release ASTE-Data-v1. Later, it is found that not all triplets are annotated (Xu et al., 2020; Wu et al., 2020). Therefore, Xu et al. (2020) refine these datasets and release ASTE-Data-v2. We compare our approach with previous methods and perform the ablation study on ASTE-Data-v2. Its data statistics is detailed in Table 1.

We also evaluate our approach on ASTE-Data-v1. Additionally, we run our approach on the Aspect-Opinion Pair Extraction (AOPE) task, which is a similar task to ASTE. We compare our approach with previous methods on two AOPE-Data (Fan et al., 2019; Chen et al., 2020). These results are presented in Appendix A.2 and A.3.

3.2 Implementation Details

We adopt `BERT-base-uncased` (Devlin et al., 2019) as the default language encoder, which consists of 12 Transformer blocks with a hidden size of 768. The number of layers of the table encoder is set to 2. We set $t = 64$, $z = 0.3$, and $k_{min} = 5$. We train the model for 10 epochs and select the best model according to the performance on the development set. We run our approach five times with different random seeds and report the average results (F_1-score).

3.3 Baselines

We categorize the baselines into four groups: table-filling methods, span-based methods, generative methods, and other methods.

Table-Filling methods represent aspect terms and opinion terms along with their sentiment relations as word-pair relations. Wu et al. (2020) propose Grid Tagging Scheme (GTS) and design an inference strategy to exploit mutual indication between different opinion factors. Zhang et al. (2020) propose a multi-task learning framework (OTE-MTL) to jointly extract terms and parse sentiment dependencies. Dual-Encoder (Jing et al., 2021) and TGA +SFI (Wang et al., 2021a) learn the sequence representation and the table representation via *table-sequence* encoders. Chen et al. (2022) propose an Enhanced Multi-Channel Graph Convolutional Network model (EMC-GCN) to utilize linguistic features.

Span-Based methods perform term extraction and relation classification through the shared span representations. Span-ASTE (Xu et al., 2021) introduces a dual-channel span pruning strategy to ease the high computational cost caused by span enumeration. SSJE (Li et al., 2022a) utilizes a Graph Convolutional Network (GCN) on the syntactic dependency tree of the sentence to enhance the span representations.

Generative methods generally convert the ASTE task into the index generation problem, including PASTE (Mukherjee et al., 2021), Span-BART (Yan et al., 2021), GAS (Zhang et al., 2021c), Paraphrase (Zhang et al., 2021b), and UIE (Lu et al., 2022).

Others Peng et al. (2020) divide the triplet extraction into two stages and then learn two separate models. Xu et al. (2020) present a position-aware tagging scheme for ASTE and accordingly propose a joint approach, JET. Chen et al. (2021a) transform the ASTE task into the multi-turn machine reading comprehension (MRC) task and address it through a bidirectional MRC (BMRC) framework. Yu Bai Jian et al. (2021) present ASTE-RL by treating the aspect and opinion terms as arguments of the expressed sentiment in a hierarchical reinforcement learning (RL) framework.

3.4 Main Results

Table 2 lists the comparison results on the ASTE task. According to these results, our approach consistently attains the best performance, demonstrating its effectiveness. More specifically, we have following observations. (1) Our approach achieves F_1-score improvements of 2.50%, 2.36%, 2.85%, and 2.01% on the four datasets compared with the previous best baseline model without introducing the syntactic dependency tree (Xu et al., 2021). (2) Although Li et al. (2022a) introduce

Model	**Rest 14**			**Lap 14**			**Rest 15**			**Rest 16**		
	$P.$	$R.$	F_1	$P.$	$R.$	F_1	$P.$	$R.$	F_1	$P.$	$R.$	F_1
Two-stage†(Peng et al., 2020)	43.24	63.66	51.46	37.38	50.38	42.87	48.07	57.51	52.32	46.96	64.24	54.21
JET$^{o}_{M=6}$(BERT)(Xu et al., 2020)	70.56	55.94	62.40	55.39	47.33	51.04	64.45	51.96	57.53	70.42	58.37	63.83
BMRC*(Chen et al., 2021a)	72.17	65.43	68.64	65.91	52.15	58.18	62.48	55.55	58.79	69.87	65.68	67.35
ASTE-RL(Yu Bai Jian et al., 2021)	70.60	68.65	69.61	64.80	54.99	59.50	65.45	60.29	62.72	67.21	69.69	68.42
PASTE$_{AF}$(Mukherjee et al., 2021)	66.70	66.50	66.60	61.20	53.60	57.10	61.70	60.80	61.30	66.10	69.80	67.90
Table-Filling Approaches												
OTE-MTL$^{\natural}$(Zhang et al., 2020)	62.70	57.10	59.71	49.62	41.07	44.78	55.63	42.51	47.94	60.95	53.35	56.82
GTS-BERT$^{\natural}$(Wu et al., 2020)	67.76	67.29	67.50	57.82	51.32	54.36	62.59	57.94	60.15	66.08	66.91	67.93
Double-Encoder(Jing et al., 2021)	67.95	71.23	69.55	62.12	56.38	59.11	58.55	60.00	59.27	70.65	70.23	70.44
TGA+SFI(Wang et al., 2021a)	71.75	70.52	71.13	65.25	53.79	58.98	62.77	59.79	61.25	68.20	69.26	68.73
EMC-GCN(Chen et al., 2022)	71.21	72.39	71.78	61.70	56.26	58.81	61.54	62.47	61.93	65.62	71.30	68.33
Span-Based Approaches												
Span-ASTE(Xu et al., 2021)	72.89	70.89	71.85	63.44	55.84	59.38	62.18	64.45	63.27	69.45	71.17	70.26
SSJE(Li et al., 2022a)	73.12	71.43	72.26	67.43	54.71	60.41	63.94	66.17	65.05	70.82	72.00	71.38
SSJE w/o GCN(Li et al., 2022a)	73.45	69.32	71.33	62.70	56.56	59.48	61.43	63.71	62.55	69.01	70.62	69.81
BDTF (Ours)	**75.53**	**73.24**	**74.35**	**68.94**	55.97	**61.74**	**68.76**	63.71	**66.12**	**71.44**	**73.13**	**72.27**

Table 2: Results on ASTE-Data-v2 (Xu et al., 2020) (%). The results with † are retrieved from Xu et al. (2020). The results with ♮ and $*$ are reproduced by Xu et al. (2021) and Yu Bai Jian et al. (2021). All the above results except Peng et al. (2020) and Zhang et al. (2020) are obtained with `BERT-base-uncased` as the language encoder.

Model	**PreTrained Model**	**#Params**	**Rest 14**	**Lap 14**	**Rest 15**	**Rest 16**	**AVG**
Span-BART(Yan et al., 2021)	`BART-base`	139M	65.25	58.69	59.26	67.62	61.71
GAS(Zhang et al., 2021c)	`T5-base`	223M	72.16	60.78	62.10	70.10	66.29
Paraphrase(Zhang et al., 2021b)	`T5-base`	223M	72.03	61.13	62.56	71.70	66.86
Double-Encoder(Jing et al., 2021)	`BERT-base-uncased`	109M	69.55	59.11	59.27	70.44	64.59
	`ALBERT-xxlarge-v1`	223M	74.82	63.30	67.67	72.01	69.45
SSI+SEL(Lu et al., 2022)	`T5-v1.1-base`	223M	71.27	58.69	59.60	70.24	64.95
	`UIE-base`	223M	72.55	62.94	64.41	72.86	68.19
	`UIE-large`	750M	74.52	63.88	67.15	75.07	70.16
BDTF (Ours)	`BART-base.encoder`	82M	74.79	62.46	64.64	70.45	68.09
BDTF (Ours)	`BERT-base-uncased`	109M	74.35	61.74	66.12	72.27	68.62
BDTF (Ours)	`RoBERTa-base`	125M	75.20	64.08	67.64	74.15	70.27
BDTF (Ours)	`DeBERTa-v3-base`	184M	**75.48**	**66.71**	**68.22**	**75.36**	**71.44**

Table 3: Comparison results with different pre-trained models (F_1-score, %).

the additional word dependency information in representation learning through Graph Convolutional Network (GCN), our approach still outperforms their approach. (3) Compared with the previous Table-Filling approaches (Zhang et al., 2020; Wu et al., 2020; Jing et al., 2021; Wang et al., 2021a; Chen et al., 2022), our approach shows substantial improvements in F_1-score. These improvements in F_1-score are more attributable to the improvements in *Precision*. For example, compared with Jing et al. (2021), our approach obtains F_1-score gains of 4.80%, 2.63%, and 6.80% for Rest14, Lap14, and Rest15, while the corresponding *Precision* gains reach 7.58%, 6.82%, and 10.21%. This suggests that our approach produces fewer wrong predictions due to its boundary sensitivity.

Many works (especially generative methods) adopt Pre-trained Language Models (PLMs) other than `BERT-base-uncased` as the backbone. Therefore, we implement our approach with different PLMs and present the results in Table 3. These results show that PLM has a significant impact on model performance. For our approach, replacing BERT with RoBERTa (Liu et al., 2019) can directly bring about 1.5% F_1-score improvement. Besides, we observe that, even with the encoder of `BART-base`, our approach can outperform most methods using `base`-size PLMs. When

Model	Rest 14				Lap 14				Rest 15				Rest 16			
	$B.$	R_S	R_M	$O.$	$B.$	R_S	R_M	$O.$	$B.$	R_S	R_M	$O.$	$B.$	R_S	R_M	$O.$
TF$_{GTS}$	10.16	2.35	6.02	12.98	11.75	5.18	7.97	16.14	14.37	2.52	6.02	18.25	9.21	4.24	4.42	14.36
BDTF	6.77	2.19	3.33	11.34	6.03	5.36	6.70	12.95	10.50	3.06	4.16	12.69	5.34	3.36	4.35	13.04
Δ	-3.39	-0.16	-2.69	-1.64	-5.75	+0.18	-1.27	-3.19	-3.87	+0.54	-1.86	-5.56	-3.87	-0.88	-0.07	-1.32

Table 4: Analysis of the wrong predictions produced by different table-filling approaches. $B.$, R_S, R_M and $O.$ denote the proportion of boundary error, single-word relation error, multi-word relation error, and other errors in all predictions, respectively.

Decoding	Rest 14	Lap 14	Rest 15	Rest 16	AVG-Δ
TF$_{GTS}$	<u>70.00</u>	<u>56.60</u>	59.58	<u>68.75</u>	-
TF$_{Double}$	69.04	54.98	<u>59.75</u>	67.61	-
BDTF(Ours)	**74.35**	**61.74**	**66.12**	**72.27**	**+4.85**

Table 5: Comparison of the table-filling approaches (F_1-score, %).

using `DeBERTa-v3-base` (He et al., 2021) as the backbone, our approach consistently achieves the best performance, even surpassing the previous methods using the `large`-size PLMs. These results show the superiority of the proposed approach.

Additionally, we evaluate our approach on ASTE-Data-v1 (Peng et al., 2020) and two AOPE-Data (Fan et al., 2019; Chen et al., 2020). These results are detailed in the Appendix A.2 and A.3. Briefly, our approach also achieves the best performance on these datasets.

3.5 Ablation Studies

3.5.1 Comparison of Table-Filling Approaches

To verify the effectiveness of our proposed table-filling approach, we replace our extraction module with TF$_{GTS}$ (Wu et al., 2020) and TF$_{Double}$[6] (Jing et al., 2021) while keeping the rest of the model unchanged.

As shown in Table 5, our table-filling approach significantly outperforms the previous table-filling approaches on all four datasets. The average F_1-score improvement is 4.85%. Notice that there are a few overlapping cases between aspect terms and opinion terms in the ASTE-Data-v2. Both TF$_{GTS}$ and TF$_{Double}$ suffer from this issue[7], but our approach can successfully solve it. This is one reason why our approach outperforms them.

To verify boundary sensitivity of our approach, we perform a detailed analysis of the wrong predictions. We first categorize the wrong predictions into three types: *boundary errors*, *relation errors*, and other errors. When the aspect term or opinion term of an extracted triplet is boundary-misspecified, we categorize it as a boundary error. When the boundary of a triplet is completely correct, but the sentiment relation is incorrectly identified, we categorize it as a relation error. Relation errors are further divided into single-word and multi-word errors. We count the proportion of each type of error in the predictions and list the results in Table 4. It can be observed that, compared with the previous table-filling approaches, our approach significantly reduces the number of boundary errors in the predictions. The proportion of boundary errors on Lap14 is reduced by about half. This shows that our approach effectively filters those boundary-misspecified triplets. Furthermore, our approach also reduces the proportion of relation errors, especially on multi-word relations. This may be due to its relation consistency.

3.5.2 Relation Learning Analysis

We conduct an ablation experiment to explore the effects of the components of relation representation learning. As shown in Table 7, the model performs poorly when the relation representation is obtained only by feature concatenation. Adding context, tensor-based operation, or CNN results in significant performance improvements. Adding these three components together improves the average performance by 8.71%. This demonstrates the necessity of each component and the overall effectiveness of our relation representation learning approach.

[6]TF$_{Double}$ utilizes two distinct encoders to learn sequence representation and table representation separately. In our implementation, we take the contextualized representation output by BERT as the sequence representation.

[7]Neither TF$_{GTS}$ nor TF$_{Double}$ account for overlapping cases in their original implementations, and thus some triplets are ignored when calculating metrics, which makes their published performance inflated. Our implementation fixes this issue.

Review	Ground-truth	**TF**$_{Double}$	**BDTF**(Ours)
The downstairs bar scene is very cool and chill.	{downstairs bar scene, cool, POS} {downstairs bar scene, chill, POS}	{downstairs, cool, POS} {downstairs, chill, POS} {bar scene, cool, POS} {bar scene, chill, POS}	{downstairs bar scene, cool, POS} {downstairs bar scene, chill, POS}
new hamburger with special sauce is ok - at least better than big mac!	{new hamburger with special sauce, ok, POS} {big mac, better than, NEG}	{hamburger, ok, POS} {big mac, better, POS}	$\emptyset$
The menu is interesting and quite reasonably priced.	{menu, interesting, POS} {menu, reasonably priced, POS} {priced, reasonably, POS}	{menu, interesting, POS} {menu, reasonably priced, POS}	{menu, interesting, POS} {menu, reasonably priced, POS} {priced, reasonably, POS}
However , I can refute that OSX is "FAST".	{OSX, FAST, NEG}	{OSX, FAST, POS}	{OSX, FAST, POS}
i love their chicken pasta cant remember the name but is sooo good.	{chicken pasta, love, POS}	{chicken pasta, love, POS} {chicken pasta, good, POS}	{chicken pasta, love, POS} {chicken pasta, good, POS}

Table 6: Case study.

Model	Rest 14	Lap 14	Rest 15	Rest 16	AVG-Δ
Concat	68.13	52.31	55.11	64.09	-
Concat + Context	72.96	59.25	64.96	72.12	+7.41
Concat + Tensor	71.63	58.78	63.77	70.17	+6.18
Concat + CNN	71.91	55.01	64.81	69.39	+5.37
Full Model	**74.35**	**61.74**	**66.12**	**72.27**	**+8.71**
Concat + Add	67.78	53.43	57.78	65.63	+1.24
Concat + Sub	69.56	52.49	55.97	66.27	+1.16
Concat + Mul	69.80	53.34	58.08	66.76	+2.08

Table 7: Ablation study on relation-level representation learning (F_1-score, %). *Concat* refers to performing a nonlinear projection on the concatenation of two word-level representations.

In addition, we also compare some element-wise operations (Bordes et al., 2013): *addition*, *subtraction*, and *multiplication*. As shown in Table 7, their performance improvements are not significant enough and sometimes even negative. This suggests that simple vector operations are insufficient to learn the relation-level information between words.

3.6 Case Study

We analyze and discuss our approach through several representative examples from the test set, presented in Table 6.

The first two examples indicate that our approach produces fewer boundary errors than the previous table-filling method. Especially in the $2nd$ example, the aspect terms and opinion terms are difficult to identify correctly. TF$_{Double}$ outputs boundary-misspecified triplets given boundary-misspecified aspect terms and opinion terms, while our approach rejects these boundary errors as expected. We believe future work could attempt to correct these boundary errors. The $3rd$ example presents an overlapping case of aspect terms and opinion terms. The previous table-filling method fails to deal with the overlapping case, but our approach successfully solves it. In the $4th$ example, although *FAST* is a positive word, *refute* reverses the corresponding sentiment polarity. Both our approach and TF$_{Double}$ make the wrong prediction, suggesting that more sentiment knowledge is required to improve the modeling ability for sentiment expressions. The $5th$ example reflects the worrying problem of incomplete annotation in the existing datasets.

4 Related Work

4.1 Aspect-Opinion Co-Extraction

In recent years, Aspect-Based Sentiment Analysis has attracted lots of researchers' interest (He et al., 2019; Yan et al., 2021; Zhang et al., 2021c; Liang et al., 2021; Mao et al., 2021; Liang et al., 2022a,b; Cao et al., 2022). As one of the most fundamental task in ABSA, Aspect term extraction has been studied in many prior works (Hu and Liu, 2004; Yin et al., 2016; Xu et al., 2018; Hu et al., 2019; Wei et al., 2020; Wang et al., 2021b). The sentiment expression of aspect terms often depends on opinion terms, and thus opinion terms can be applied as clues to extract aspect terms and determine corresponding sentiment polarity. As a result, the amount of related aspect and opinion co-extraction work has been gradually increasing (Wang et al., 2016, 2017; Li and Lam, 2017; Li et al., 2018; Fan et al., 2019; Chen et al., 2020; Zhao et al., 2020).

To explicitly capture the relation between aspect and opinion terms, Fan et al. (2019) introduce a new task, Target-oriented Opinion Words Extraction (TOWE), which aims to extract the corresponding opinion words (*i.e.*, opinion terms) for a given target (*i.e.*, aspect term). Furthermore, Peng et al. (2020) present the Aspect Sentiment Triplet Extraction (ASTE) task.

Subsequent works address the ASTE task by transforming it into the position-aware tagging problem (Xu et al., 2020), the machine reading comprehension task (Chen et al., 2021a; Mao et al., 2021), the table-filling problem (Wu et al., 2020; Zhang et al., 2020; Chen et al., 2021b; Jing et al., 2021; Chen et al., 2022), the span-relation extraction problem (Xu et al., 2021; Li et al., 2022a), and the sequence generation task (Yan et al., 2021; Zhang et al., 2021c; Mukherjee et al., 2021; Lu et al., 2022).

4.2 Table-Filling Approach

The table-filling approach is initially proposed for joint entity and relation extraction. Miwa and Sasaki (2014) first cast joint entity and relation extraction as a table-filling problem. Gupta et al. (2016) improve it by a bi-RNN structure. Zhang et al. (2017) introduce global normalization and syntactic features. Similarly, Adel and Schütze (2017) jointly normalize all predictions of table-filling through the extension of the linear-chain CRF. The above methods first encode the text sequence and then obtain the table representation by feature concatenation. For a stronger table representation, Tran and Kavuluru (2019) and Wang and Lu (2020) employ CNNs and Multi-Dimensional RNNs (MDRNNs) as the table encoder.

5 Conclusion

This paper proposes a Boundary-Driven Table-Filling (BDTF) approach for the Aspect Sentiment Triplet Extraction (ASTE) task. BDTF transforms the ASTE task into detection and classification of relation regions in a two-dimensional table, solving the problems of *relation inconsistency* and *boundary insensitivity* in previous table-filling methods. In addition, to support BDTF, this paper develops an effective relation learning approach to learn the table representation, which can fully exploit word-to-word interactions and relation-to-relation interactions. Experiments on several public datasets show that our approach significantly outperforms existing methods. Further analysis shows that our approach produces fewer boundary errors and can solve the overlapping issue that previous table-filling approaches suffer from. Ablation study demonstrates the effectiveness of each component in the relation representation learning approach.

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Limitations

Even though the proposed approach significantly outperforms previous methods on several public benchmarks, it suffers from the following limitations:

- The table-filling methods need to construct a two-dimensional table representation of word-pair relations. If the vector dimensions are the same, the size of the table representation will be significantly larger than that of the sequence representation. Therefore, compared to other methods, the table-filling methods take up more memory. This problem also appears in our approach. Detailed memory usage and training time are presented in Appendix A.4.

- The proposed approach has lower recall than precision. This is because our approach significantly reduces wrong predictions but does not increase correct predictions by much.

We believe that addressing the above limitations without compromising the original advantages can further improve the model.

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A Additional Results

A.1 Datasets and Experiment Settings

We additionally evaluate our approach on ASTE-Data-v1 (Peng et al., 2020) and two AOPE-Data (Fan et al., 2019; Chen et al., 2020). Their statistics are detailed in Table 8.

On the two AOPE-Data, the validation set is not explicitly defined. For a fair comparison, we follow the settings of previous works (Chen et al., 2020; Wu et al., 2020). For the AOPE-Data provided by Fan et al. (2019), we randomly select 20% of the training set as the validation set; for the AOPE-Data provided by Chen et al. (2020), we publish the best results on the test set. All results are the average of 5 runs.

Provider	**Dataset**	**Split**	**#Sent**	**#A**	**#O**	**#P/#T**
Peng et al. (2020)	**Rest 14**	Train	1300	2079	2145	2145
		Dev	323	530	524	524
		Test	496	849	862	862
	Lap 14	Train	920	1283	1265	1265
		Dev	228	317	337	337
		Test	339	475	490	490
	Rest 15	Train	593	834	923	923
		Dev	148	225	238	238
		Test	318	426	455	455
	Rest 16	Train	842	1183	1289	1289
		Dev	210	291	316	316
		Test	320	444	465	465
Fan et al. (2019)	**Rest 14**	Train	1625	2539	2722	3062
		Test	500	864	888	1030
	Lap 14	Train	1151	1626	1625	1871
		Test	343	481	498	565
	Rest 15	Train	754	1076	1192	1871
		Test	325	436	469	493
	Rest 16	Train	1079	1512	1661	1770
		Test	329	456	485	524
Chen et al. (2020)	**Rest 14**	Train	3041	3693	3512	2809
		Test	800	1134	1014	936
	Lap 14	Train	3045	2359	2500	1535
		Test	800	653	677	380
	Rest 15	Train	1315	1205	1217	1231
		Test	685	542	516	516

Table 8: Statistics of ASTE-Data-v1 (Peng et al., 2020) and two AOPE-Data (Fan et al., 2019; Chen et al., 2020). #Sent, #A, #O, #P, and #T represent the number of sentences, aspect terms, opinion terms, pairs, and triplets, respectively.

A.2 Results on ASTE-Data-v1

The experimental results on ASTE-Data-v1 are presented in Table 9. According to these results, our approach consistently achieves the best performance in F_1-score.

A.3 Results on Aspect-Opinion Pair Extraction

Aspect-Opinion Pair Extraction (AOPE) aims to extract aspect terms and opinion terms along with their relations. The only difference between AOPE and ASTE is that the sentiment is

Model	Rest 14			Lap 14			Rest 15			Rest 16		
	$P.$	$R.$	F_1	$P.$	$R.$	F_1	$P.$	$R.$	F_1	$P.$	$R.$	F_1
Two-stage(Peng et al., 2020)	44.18	62.99	51.89	40.40	47.24	43.50	40.97	54.68	46.79	46.76	62.97	53.62
OTE-MTL(Zhang et al., 2020)	66.04	56.25	60.62	50.52	39.71	44.31	57.51	43.96	49.76	64.68	54.97	59.36
JET$^o_{M=6}$(BERT)(Xu et al., 2020)	67.97	60.32	63.92	58.47	43.67	50.00	58.35	51.43	54.67	64.77	61.29	62.98
GTS-BERT(Wu et al., 2020)	70.92	69.49	70.20	57.52	51.92	54.58	59.29	58.07	58.67	68.58	66.60	67.58
S^{3}E^2(Chen et al., 2021b)	69.08	64.55	66.74	59.43	46.23	52.01	61.06	56.44	58.66	71.08	63.13	66.87
TOP(Huang et al., 2021)	63.59	73.44	68.16	57.84	<u>59.33</u>	58.58	54.53	<u>63.30</u>	58.59	63.57	71.98	67.52
Dual-MRC(Mao et al., 2021)	71.55	69.14	70.32	57.39	53.88	55.58	63.78	51.87	57.21	68.60	66.24	67.40
BMRC(Chen et al., 2021a)	71.32	<u>70.09</u>	70.69	<u>65.12</u>	54.41	59.27	63.71	58.63	61.05	67.74	68.56	68.13
Span-BART (Yan et al., 2021)	-	-	<u>72.46</u>	-	-	57.59	-	-	60.11	-	-	69.98
Double-Encoder(Jing et al., 2021)	73.96	67.87	70.78	65.13	57.03	<u>60.81</u>	<u>64.86</u>	<u>63.30</u>	<u>64.07</u>	<u>74.77</u>	<u>72.20</u>	<u>73.46</u>
TGA+SFI(Wang et al., 2021a)	<u>77.03</u>	67.46	71.92	62.71	54.53	58.33	64.62	60.62	62.55	68.45	70.61	69.51
BDTF(Ours)	76.71	**74.01**	**75.33**	**68.30**	55.10	**60.99**	**66.95**	**65.05**	**65.97**	73.43	**73.64**	**73.51**

Table 9: Results on ASTE-Data-v1 (Peng et al., 2020) (%).

Model	Rest 14	Lap 14	Rest 15
HAST+IOG*	63.14	58.97	58.84
JERE-MHS*	67.81	58.69	60.17
HAST+RD*	73.55	64.05	65.20
DE-CNN+RD*	71.02	61.11	64.19
IMN+RD*	73.69	62.98	65.56
SPAN+RD*	74.17	65.99	67.55
RINATE+RD*	74.34	64.17	65.42
SDRN(Chen et al., 2020)	76.48	67.13	70.94
MT-TSMSA(Feng et al., 2021)	<u>76.69</u>	<u>68.18</u>	<u>71.64</u>
BDTF (Ours)	**80.03**	**71.48**	**72.77**

Table 10: Results on Aspect-Opinion Pair Extraction on Chen et al. (2020) (F_1-score, %). The results with $*$ are retrieved from Chen et al. (2020).

not required in AOPE. Considering their similarity, we also evaluate our approach on the AOPE task. To make our approach applicable to the AOPE task, we modify the type space of relation regions from $\{\texttt{POS}, \texttt{NEU}, \texttt{NEG}, \texttt{Invalid}\}$ to $\{\texttt{Pair}, \texttt{Invalid}\}$. The corresponding experimental results are listed in Table 10 and 11. It can be observed that our approach also yields outstanding results on the AOPE task. On the dataset provided by Fan et al. (2019), many methods (Wu et al., 2021; Liu et al., 2022; Li et al., 2022a,b) introduce additional syntactic features to learn better feature representations. Although we do not use syntactic features, our approach still surpasses them, demonstrating its effectiveness.

A.4 Memory Usage & Training Time

In this section, we list the memory usage and training time for the comparison and improvement by subsequent work. We conduct experiments on Rest 14 of ASTE-Data-v2 with the batch size of 1. The results are shown in Table 12. We can observe that although the proposed BDTF substantially outperforms the previous method in F_1-score, it requires more memory to run. We believe that reducing the memory usage can further improve our approach.

Model	Rest14	Lap14	Rest15	Rest16
SpanMlt(Zhao et al., 2020)	75.60	68.66	64.48	71.78
GTS(Wu et al., 2020)	75.53	65.67	67.53	74.62
SDRN*(Chen et al., 2020)	74.91	68.50	70.08	76.92
LAGCN(Wu et al., 2021)	76.62	68.88	68.91	76.59
MRC-MVT(Zhang et al., 2021a)	77.02	67.35	68.63	75.99
QDSL(Gao et al., 2021)	<u>78.05</u>	70.20	71.22	77.28
MT-TSMSA(Feng et al., 2021)	78.37	69.33	69.13	78.39
STER(Zhang et al., 2022)	74.96	67.64	69.30	75.89
MAIN(Liu et al., 2022)	77.54	69.86	70.92	77.97
SRGT(Li et al., 2022b)	76.78	70.47	<u>71.92</u>	<u>79.36</u>
SSJE(Li et al., 2022a)	78.02	<u>72.51</u>	69.53	78.96
BDTF (Ours)	**79.39**	**72.92**	**72.62**	**79.65**

Table 11: Results of Aspect-Opinion Pair Extraction on Fan et al. (2019) (F_1-score, %). The results with $*$ are retrieved from Feng et al. (2021).

Model	Memory Usage	Training Time	F_1(%)
Span-ASTE	3173MB	108 seconds	71.62
BDTF(d=32)	6117MB	128 seconds	74.34
BDTF(d=64)	8103MB	135 seconds	74.73

Table 12: The comparison of memory usage and training time. We train these models on a single Tesla V100 32GB. *Training time* refers to the time it takes to train a model for one epoch on the training set.