Machine Translation based on Predicate-Argument Structure

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Outline

1. Introduction
2. Syntax-Complemented PAS
3. Transformation Rule Extraction
4. ATT Framework
5. Decoder
6. Experiment
7. Conclusion
1. Introduction

◆ Current Translation Models
  ▪ Word-based Translation Model
    ○ Brown et al., 1993
  ▪ Phrase-based Translation Model
    ○ Koehn et al., 2003
    ○ Och and Ney, 2004
  ▪ Syntax-based Translation Model
    ○ Galley et al., 2006;
    ○ Liu et al., 2006;
    ○ Marcu et al., 2006
    ...

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1. Introduction
1. Introduction

◆ How to represent the meanings of a sentence?

**Predicate-Argument Structure (PAS)**

- A PAS consists of a predicate and several associated arguments.
- The semantic relation between the predicate and its arguments is annotated.

This plan will provide tax concessions to the working masses.

PAS for Chinese predicate “提供”
1. Introduction

We can see:

- PAS Indicates the skeleton structure and shallow semantic information of sentence
- PAS of both source side and target side are more consistent with each other than syntactic structures [Fung et al., 2006; Wu and Fung, 2009]
- Compared with syntactic structure, PAS will be a better alternative for building translation models
1. Introduction

◆ Existing work on PAS for SMT

(1) Pre-process or post-process

- [Komachi and Matsumoto, 2006]
- [Wu and Fung, 2009]

■ The weakness:

➢ PAS is only used before or after decoding, rather than integrated into the decoder.

➢ Cannot handle the erroneous PAS, considering current PAS analysing system is not such satisfied.
1. Introduction

(2) Utilizing semantic role labeling tags to refine the non-terminals of syntax-based SMT

- [Liu and Gildea, 2008]
- [Gao and Vogel, 2011]

The weakness:

- Only utilize the semantic roles to refine the syntax tags.
- The core of PAS, i.e., its skeleton property and semantic property, is not effectively accessed during translation.
1. Introduction

(3) Design proper PAS-based features to constrain translation candidates

- [Liu and Gildea, 2010]
- [Xiong et al., 2012]

The weakness:

- Do not consider the PAS as an entire semantic structure in the decoder
- The property of structure consistency between languages in PAS is not effectively modeled
- Reordering is only based on partial PAS
1. Introduction

In summary:

The existing approaches just introduce some additional information for existing translation models. There is not a translation model built based on PAS.
1. Introduction

We propose an Analysis-Transformation-Translation (ATT) framework:

- Analysis
- Transformation
- Translation
  - Element translation
  - Translation by global reordering
1. Introduction

■ Step-1: Analysis

Semantic role labelling (SRL) on the input sentences to get source-side PASs

This plan will provide tax concessions to the working masses.

此 项 计划 将 对 劳动 大众 提供 减税 优惠


Source-side PAS(提供, provide)

Analysis
1. Introduction

- **Step-2: Transformation**

Convert the source-side PASs to target-side-like PASs by **predicate-aware PAS transformation rules**

![Diagram showing transformation from source-side PAS to target-side-like PAS]

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1. Introduction

- **Step-3: Translation**

  *(a)Element translation:* translate each source element (source predicate or argument) respectively

**Source elements:**

- [A0]: 此项计划
- [AM-ADV]: 将
- [A2]: 对劳动大众
- [Pred]: 提供
- [A1]: 减税优惠

**Translation candidates of source elements:**

- [A0]: this project / this plan / ...
- [AM-ADV]: will / ...
- [A2]: to public / to the working masses /
- [Pred]: provide / to provide / ...
- [A1]: tax concessions / ...
1. Introduction

(b) Translation by global reordering: combine the translation candidates of source elements to get the final translation based on the target-side-like PAS

Translation candidates of source elements:

[A0]_1: this project / this plan / ...
[AM-ADV]_2: will / ...
[A2]_3: to public / to the working masses / ...
[Pred]_4: provide / to provide / ...
[A1]_5: tax concessions / ...

Target-side-like PAS

X₁ X₂ X₄ X₅ X₃

(b) Translation by global reordering

this plan / will / provide / tax concessions / to the working masses
1. Introduction

◆ The strongpoints of ATT framework:

➢ The translation process transforms the skeleton structure of the source sentence into the skeleton of target language

➢ It works similar to a human translator to some extent

It is a big step towards semantics-based machine translation
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2. Syntax-Complemented PAS

◆ The problem of PAS

In a PAS representation, the adjacent elements are usually separated by gap strings.
2. Syntax-Complemented PAS

◆ The problem of PAS

In a PAS representation, the adjacent elements are usually separated by gap strings.

ARG0

奥运村 的 位置
the location of the olympic village

ARG1

对 运动员
for athletes

Pred

是
is

the best

the best
2. Syntax-Complemented PAS

◆ The problem of PAS

In a PAS representation, the adjacent elements are usually separated by gap strings.

source-side PAS(是)


ARG0

奥运村的位置
the location of the olympic village

Pred

对
is

ARG1

运动员
for athletes

最好的
the best

The problem of PAS

In a PAS representation, the adjacent elements are usually separated by gap strings.

source-side PAS(是)


ARG0

奥运村的位置
the location of the olympic village

Pred

对
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ARG1

运动员
for athletes

最好的
the best

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2. Syntax-Complemented PAS

◆ The problem of PAS

In a PAS representation, the adjacent elements are usually separated by gap strings.

![Diagram showing source-side PAS and the problem of PAS](image)

- **ARG0**: 奥运村的位置 (the location of the olympic village)
- **AM-PRP**: 对运动员 (for athletes)
- **Pred**: 是 (is)
- **ARG1**: 最好的 (the best)
2. Syntax-Complemented PAS

◆ The problem of PAS

In a PAS representation, the adjacent elements are usually separated by gap strings.

The problem of PAS

In a PAS representation, the adjacent elements are usually separated by gap strings.
2. Syntax-Complemented PAS

Syntax-Complemented PAS(SC-PAS)

- A combination of PAS and syntax. We employ syntax information to model the gap strings of PAS
- SC-PAS could effectively overcome the drawback of the prevalent gaps in PAS, and provides more useful knowledge for translation
2. Syntax-Complemented PAS

◆ Inside Context

奥运村 的 位置 对 运动员 是 最 好 的
ao-yun-cun de wei-zhi dui yun-dong-yuan shi zui hao de

ARG0 Pred ARG1
2. Syntax-Complemented PAS

◆ Inside Context

奥运村 的 位置 对 运动员 是 最 好 的

AO-yun-cun de wei-zhi dui yun-dong-yuan shi zui hao de

ARG0 Pred ARG1

closure_range
2. Syntax-Complemented PAS

◆ Inside Context

奥运村的运动员是运动员
位置的对运动员是运动员
最 好 的

AO

Inside Context

Pred

ARG1

closure_range
2. Syntax-Complemented PAS

◆ **s-tag sequence**: the sequence of the highest root categories that exactly dominates the tree fragments
2. Syntax-Complemented PAS

◆ s-tag sequence: the sequence of the highest root categories that exactly dominates the tree fragments

s-tag sequence: VC CP

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2. Syntax-Complemented PAS

♦ **s-tag sequence**: the sequence of highest root categories that exactly dominates the tree fragments

♦ Abstract the **Inside Context (IC)** by the s-tag sequence of its corresponding span

```
s-tag sequence: PP
```

```
PP
  VP
    PP
      P
      NN
dui
yun-dong-yuan
for athletes

VC
  CP
    AD
    VA
    DEC
shi
zui
hao
de

zui 9
hao 10
de 11

for athletes is the best
```

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2. Syntax-Complemented PAS

奥运村 的 位置 对 运动员 是 最 好 的
ao-yun-cun de wei-zhi dui yun-dong-yuan shi zui hao de

The location of the Olympic village for athletes is the best

ARG0
Pred
ARG1
2. Syntax-Complemented PAS

The location of the Olympic village for athletes is the best.
2. Syntax-Complemented PAS

The location of the Olympic village for athletes is the best.

Syntax-complemented PAS (SC-PAS)
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3. Transformation Rule Extraction

source-side PAS (是)  \[\text{[A0]}_1 \quad \text{[Pred]}_2 \quad \text{[A1]}_3\]  

\[\quad \leftrightarrow \quad \]

target-side-like PAS \[\text{[X]}_1 \quad \text{[X]}_2 \quad \text{[X]}_3\]
3. Transformation Rule Extraction

- **Pred**: the predicate where the rule is extracted
- **SP**: the source-side PAS, i.e., the list of source elements in source language order
3. Transformation Rule Extraction

- **Pred**: the predicate where the rule is extracted
- **SP**: the source-side PAS, i.e., the list of source elements in source language order
- **TP**: the target-side-like PAS, i.e., a list of general non-terminals in target language order.
3. Transformation Rule Extraction

◆ Example ①

The Chinese red cross society will provide emergency humanitarian assistance to Palestine.
3. Transformation Rule Extraction

◆ Example ①

The Chinese red cross society will provide emergency humanitarian assistance to Palestine.
3. Transformation Rule Extraction

◆ Example ①

The Chinese red cross society will provide emergency humanitarian assistance to Palestine.

zhong-guo hong-shi-zi-hui jiang xiang ba-le-si-tan ti-gong jin-jin ren-dao zhu-yi yuan-zhu

The Chinese red cross society will provide emergency humanitarian assistance to Palestine.
3. Transformation Rule Extraction

◆ Example ①

The Chinese red cross society will provide emergency humanitarian assistance to Palestine.

Source-side PAS (提供)

Target-side-like PAS

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3. Transformation Rule Extraction

◆ Example ②

[the location of the olympic village]₁ [is]₃ [the best]₄ [for athletes]₂

source-side PAS(是)


[SC-PAS-based Transformation Rule]

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3. Transformation Rule Extraction

◆ Examples of PAS transformation rule

Reordering PAS Transformation Rules

<table>
<thead>
<tr>
<th>Pred</th>
<th>SP</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>关心(concern)</td>
<td>[AM-ADV]₂ [Pred]₃ [A1]₁</td>
<td>X₃ X₁ X₂</td>
</tr>
<tr>
<td>提供(provide)</td>
<td>[A0]₁ [A2]₂ [Pred]₃ [A1]₄</td>
<td>X₁ X₃ X₄ X₂</td>
</tr>
</tbody>
</table>

Monolingual PAS Transformation Rules

<table>
<thead>
<tr>
<th>Pred</th>
<th>SP</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>是(is)</td>
<td>[A0]₁ [Pred]₂ [A1]₃</td>
<td>X₁ X₂ X₃</td>
</tr>
<tr>
<td>希望(hope)</td>
<td>[A0]₁ [Pred]₂ [A1]₃</td>
<td>X₁ X₂ X₃</td>
</tr>
</tbody>
</table>
3. Transformation Rule Extraction

◆ Example SC-PAS Transformation Rule

<table>
<thead>
<tr>
<th>Pred</th>
<th>SP</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>是(is)</td>
<td>[A0]₁ [PP]₂ [Pred]₃ [A1]₄</td>
<td>X₁ X₃ X₄ X₂</td>
</tr>
<tr>
<td>举行(hold)</td>
<td>[AM-TMP]₁ [PP]₂ [Pred]₃</td>
<td>X₃ X₂ X₁</td>
</tr>
</tbody>
</table>
Outline

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4. ATT Framework

Step 1: Analysis

SRL on the test sentences

● 3 parse trees (Berkeley Parser: 3-best)

\[ P_1: \quad [\quad A0 \quad ] \quad [AM-ADV] \quad [\quad A2 \quad ] \quad [Pred] \quad [\quad A1 \quad ] \]
\[ P_2: \quad [AM-ADV] \quad [\quad A0 \quad ] \quad [AM-ADV] \quad [\quad A2 \quad ] \quad [Pred] \quad [\quad A1 \quad ] \]
\[ P_3: \quad [AM-ADV] \quad [\quad A0 \quad ] \quad [AM-ADV] \quad [\quad A2 \quad ] \quad [Pred] \quad [\quad A1 \quad ] \]

Bush said this plan will provide tax concessions to the working masses.
4. ATT Framework

Step 2: Transformation

● Match the source-side PASs from the analysis step with the PAS transformation rules and get the target-side-like PASs

Bush said this plan will provide tax concessions to the working masses.
4. ATT Framework

Step 2: Transformation

- Match the source-side PASs from the analysis step with the PAS transformation rules and get the target-side-like PASs

\[
P_1: \quad [A0] \ [AM-ADV] \ [A2] \ [Pred] \ [A1]
P_2: \quad [AM-ADV] \ [A0] \ [AM-ADV] \ [A2] \ [Pred] \ [A1]
P_3: \quad [AM-ADV] \ [A0] \ [AM-ADV] \ [A2] \ [Pred] \ [A1]
\]

Source-side PAS (提供)  Target-side-like PAS

[AM-ADV]_2  [A2]_3  [Pred]_4  [A1]_5  X_1  X_2  X_4  X_5  X_3

布什_1  说_2  此_3  项_4  计划_5  将_6  对_7  劳动_8  大众_9  提供_10  减税_11  优惠_12
4. ATT Framework

Step 2: Transformation

● Match the source-side PASs from the analysis step with the PAS transformation rules and get the target-side-like PASs

| $P_1$: | [ | A0 ] | [AM-ADV] | [ | A2 ] | [Pred] | [ | A1 ] |
|-------|-------|---------|---------|-------|-------|-------|
| $P_2$: | [AM-ADV] | [ A0 ] | [AM-ADV] | [ | A2 ] | [Pred] | [ | A1 ] |
| $P_3$: | [AM-ADV] | [ A0 ] | [AM-ADV] | [ | A2 ] | [Pred] | [ | A1 ] |

布什1 说2 此3 项4 计划5 将6 对7 劳动8 大众9 提供10 减税11 优惠12

Source-side PAS(提供)

Target-side-like PAS

X1 X2 X4 X5 X3

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4. ATT Framework

Step 2: Transformation

- Match the source-side PASs from the analysis step with the PAS transformation rules and get the target-side-like PASs

<table>
<thead>
<tr>
<th>Source-side PAS</th>
<th>Target-side-like PAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>[A0] [AM-ADV]</td>
<td>[X1]</td>
</tr>
<tr>
<td>[AM-ADV] [A0]</td>
<td>[X2]</td>
</tr>
<tr>
<td>[AM-ADV] [A0]</td>
<td>[X4]</td>
</tr>
<tr>
<td>[AM-ADV] [A0]</td>
<td>[X5]</td>
</tr>
<tr>
<td>[AM-ADV] [A0]</td>
<td>[X3]</td>
</tr>
</tbody>
</table>

布什 说 此 项 计划 将 对 劳动 大众 提供 减税 优惠

P1: [A0] [AM-ADV] [A2] [Pred] [A1]
P2: [AM-ADV] [A0] [AM-ADV] [A2] [Pred] [A1]
P3: [AM-ADV] [A0] [AM-ADV] [A2] [Pred] [A1]
4. ATT Framework

◆ How to select target-side-like PASs?

● The same source-side PAS might play different roles or indicate different meaning in their corresponding sentences.

● One source-side PAS may correspond to several different target-side-like PASs.
4. ATT Framework

1. 防洪 是 首要的任务
   ARG0 Pred ARG1

2. 中国和俄罗斯 是 两个大国，应...
   ARG0 Pred ARG1
4. ATT Framework

1. 防洪是首要的任务
   - Flood prevention is the primary mission

2. 中国和俄罗斯是两个大国，应...
   - China and Russia are two major countries, should...

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4. ATT Framework

1. 防洪是首要的任务
   - ARG0: flood prevention
   - Pred: is
   - ARG1: the primary mission

2. 两个大国是应...
   - ARG0: two major countries
   - Pred: should
   - ARG1: China and Russia

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4. ATT Framework

1. 防洪 是 首要的任务
   \[
   \text{target-side-like PAS}
   \]
   \[
   [X_1] [X_2] [X_3]
   \]

2. 中国 和 俄罗斯 是 两个大国，应...
   \[
   \text{target-side-like PAS}
   \]
   \[
   [X_2] [X_3] [X_1]
   \]
4. ATT Framework

source PAS (是)

ARG0  Pred  ARG1

原因  是  什么

target-side-like PAS

$X_1$  $X_2$  $X_3$

$X_2$  $X_3$  $X_1$

$X_3$  $X_2$  $X_1$

...
4. ATT Framework

source PAS (是)

ARG0  Pred  ARG1

原因  是  什么

the reason  is  what

target-side-like PAS

X₁  X₂  X₃

X₂  X₃  X₁

X₃  X₂  X₁

⋯
4. ATT Framework

source PAS (是)

ARG0  Pred  ARG1

原因  是  什么

target-side-like PAS

$X_1$  $X_2$  $X_3$

$X_2$  $X_3$  $X_1$

$X_3$  $X_2$  $X_1$

...
4. ATT Framework

◆ The problem of selecting proper target-side-like PAS can be considered as a multi-class classification task.

Maximum Entropy Selection Model

source PAS (是)

ARG0  Pred  ARG1

target-side-like PAS

X_1  X_2  X_3

Lable 1

X_2  X_3  X_1

Lable 2

X_3  X_2  X_1

Lable 3

...
4. ATT Framework

◆ Maximum Entropy Selection Model

\[ P_\theta(tp \mid sp, c(sp), c(tp)) = \frac{\exp(\sum_i \theta_i h_i(sp, tp, c(sp), c(tp)))}{\sum_{tp'} \exp(\sum_i \theta_i h_i(sp, tp', c(sp), c(tp')))} \]
4. ATTT Framework

◆ Maximum Entropy Selection Model

\[
P_\theta(tp \mid sp, c(sp), c(tp)) = \frac{\exp(\sum_i \theta_i h_i(sp, tp, c(sp), c(tp)))}{\sum_{tp'} \exp(\sum_i \theta_i h_i(sp, tp, c(sp), c(tp)))}
\]

● \(sp\): source-side PAS
● \(tp\): target-side-like PAS
● \(c(sp), c(tp)\): context information on the two sides
4. ATT Framework

◆ The features

● Lexical and POS features
  - the words immediately to the left and right of $sp$
  - The head word of each argument also serves as a lexical feature
  - The corresponding POS tags of the above words
4. ATT Framework

● Predicate feature

➢ The pair of source predicate and its corresponding target predicate

\[ t-pred = \arg \max_{j \in t\_range(PAS)} p(t_j \mid s-pred) \]

✓ \( s-pred \) is the source predicate

✓ \( t-pred \) is the corresponding target predicate.

✓ \( t\_range(PAS) \) refers to the target range covering all the words that are reachable from the PAS via word alignment.
4. ATT Framework

● Syntax features

➤ The highest syntax tag for each argument
➤ The lowest father node of $sp$ in the parse tree.
4. ATT Framework

Step 3: translation

1. Element translation: Get translation candidates for each element from any translation system (BTG etc.).

This plan will provide tax concessions to the working masses.
4. ATT Framework

2. Reorder the translation candidates of elements according to the achieved target-side-like PAS.

This plan will provide tax concessions to the working masses.
4. ATT Framework

3. Combine the candidates of elements by cube pruning.

This plan will provide tax concessions to the working masses.
4. ATT Framework

However, many source elements’ spans are very short, numerous phrase translation rules are ignored during translation !!!

This plan will provide tax concessions to the working masses.
4. ATT Framework

◆ CKY style decoding strategy

More phrase translation rules can be used in this frame

This plan will provide tax concessions to the working masses.
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5. Decoder

◆ Construct a decoding hypergraph for the whole sentence

◆ **PAS span**: the span covered by a PAS.
  - use a multiple-branch hyperedge to connect that span to the PAS’s elements

◆ **non-PAS span**: the span not covered by PAS
  - consider all the binary segmentations of that span and use binary hyperedges to link them
5. Decoder

the whole sentence [1,n]

PAS span
5. Decoder

the whole sentence $[1,n]$

non-PAS span

PAS span

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5. Decoder

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5. Decoder

\[
\begin{align*}
[A0] & \mid [\text{Pred}] & [\text{A1}] \\
\text{布什说} & (\text{said}_2) & \text{此} & \text{项} & \text{计划} & \text{将} & \text{对} & \text{劳动} & \text{大众} & \text{提供} & \text{减税} & \text{优惠} \\
\text{PAS} (\text{说} (\text{said}))_{1-12} \\
[A0]_{1,1} & [\text{Pred}]_{2,2} & [\text{A1}]_{3,12} \\
\text{此} & \text{项} & \text{计划} & \text{将} & \text{对} & \text{劳动} & \text{大众} & \text{提供} (\text{provide})_{10} & \text{减税} & \text{优惠} \\
\end{align*}
\]
5. Decoder

P1: [ A0 ] [ AM-ADV ] [ A2 ] [ Pred ] [ A1 ]
P2: [ AM-ADV ] [ A0 ] [ AM-ADV ] [ A2 ] [ Pred ] [ A1 ]

此3 项4 计划5 将6 对7 劳动8 大众9 提供10 减税11 优惠12

PAS(说)1-12

[A0]1,1 [Pred]2,2 [A1]3,12 / PAS(提供)3,12


[A0]3,5

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5. Decoder

- PAS span: The ATT translation framework
- non-PAS span: BTG system
5. Decoder

<table>
<thead>
<tr>
<th>BTG</th>
<th>[甲烷] [的 温室效应] [是] [二氧化碳 的 21倍]</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane</td>
<td>is [21 times that of carbon dioxide]</td>
</tr>
<tr>
<td>greenhouse gas emissions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PAS-ATT</th>
<th>甲烷 的 温室效应 是 二氧化碳 的 21倍</th>
</tr>
</thead>
<tbody>
<tr>
<td>[A0]</td>
<td>[Pred] [A1]</td>
</tr>
<tr>
<td>greenhouse gas emissions of methane</td>
<td>is [21 times that of carbon dioxide]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference</th>
<th>[甲烷 的 温室效应] [是] [二氧化碳 的 21倍]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[the greenhouse effect of methane]</td>
<td>is [21 times that of carbon dioxide]</td>
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</table>
5. Decoder

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6. Experiment

◆ Experimental Setup

➢ Chinese-to-English translation

➢ Training set: about 2.1M sentence pairs

➢ Language model: 5-gram trained on Xinhua portion of GIGA WORD corpus and training set

➢ Development set: NIST03 (919)

➢ Test set: NIST04 (1788) and NIST05 (1082)

➢ Baseline Translation System: Moses, BTG
6. Experiment

◆ PAS-ATT : The ATT framework using PAS
◆ SC-PAS-ATT : The ATT framework using SC-PAS

<table>
<thead>
<tr>
<th>Systems</th>
<th>BLEU</th>
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<tbody>
<tr>
<td></td>
<td>MT04</td>
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<tr>
<td>Moses</td>
<td>36.21</td>
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<tr>
<td>BTG</td>
<td>37.20</td>
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<tr>
<td>PAS-ATT</td>
<td>37.50*</td>
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<td>SC-PAS-ATT</td>
<td>37.81*#</td>
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Outline

1. Introduction
2. Syntax-Complemented PAS
3. Transformation Rule Extraction
4. ATT Framework
5. Decoder
6. Experiment
7. Conclusion
7. Conclusion

◆ We have built an ATT framework to model predicate-argument structure in translation model:
  ● We analyze the weakness of PAS and propose a concept of syntax-complemented PAS (SC-PAS).
  ● We extract structure transformation rule to model the intrinsic relation between the source-side and the target-side-like PASs
  ● We divide the translation process into 3 steps: **Analysis; Transformation; Translation**.
7. Conclusion

◆ The predicate-argument structure helps to improve the translation quality in the following aspects:

● Taking advantage of PAS, the translation model keeps structure consistency well across languages.

● Using the transformation rules, the translation model performs global reordering in a skeleton scenario.

● Reasonable strategies are designed to exert the merit of PAS to segment sentences for translation.
References


References


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Thanks!
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