Syntax-Guided Controlled Generation of Paraphrases

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Kabir Ahuja  
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Partha Talukdar

Machine and Language Learning Lab  
Indian Institute of Science, Bangalore
Motivation for Syntax-Guided Paraphrasing

S1: Because it is raining today, you should carry an umbrella

S2: You should carry an umbrella today, because it is raining

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Motivation for Syntax-Guided Paraphrasing

**S1**: Because it is raining today, you should carry an umbrella

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S1: Because it is raining today, you should carry an umbrella.

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Task: Syntax-guided Paraphrasing

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S1: Because it is raining today, you should carry an umbrella
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**Task: Syntax-guided Paraphrasing**

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**Disclaimer**

All experiments conducted on English language datasets
Syntactic Paraphrase Generation

Constraining paraphrases to conform to a given syntactic exemplar
Syntactic Paraphrase Generation

Constraining paraphrases to conform to a given syntactic exemplar

| SOURCE | what are pure substances? what are some examples? |
## Syntactic Paraphrase Generation

Constraining paraphrases to conform to a given syntactic exemplar

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Constraining paraphrases to conform to a given syntactic exemplar

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| PARAPHRASE | what are some examples of pure substances? |
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Constraining paraphrases to conform to a given syntactic exemplar

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**Fidelity**

(Meaning preserving)
Syntactic Paraphrase Generation

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- **Fidelity** (Meaning preserving)
- **Syntactacticality** (Adherence to exemplar syntax)
Constituency-based parse tree syntactic information

EXEMPLAR

what is the best language for web development?
What is the best language for web development?
Utilisation of Syntactic Information
# Utilisation of Syntactic Information

| SOURCE | what are some of the mobile apps you can’t live without and why? |
## Utilisation of Syntactic Information

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* Adversarial Example Generation with Syntactically Controlled Paraphrase Networks, Iyyer et. al. 2018
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SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model
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Use Syntactic Tree Structure to Guide Paraphrase Generation model

Sentence Encoder

Syntactic Encoder

Decoder

 Sentence Encoder
how close are we
real iron man suit ?

EXEMPLAR SENTENCE

is it safe to access the deep web ?

Syntactic Encoder

PARSE TREE OF EXEMPLAR SENTENCE
H = 4

Similar Syntax

PARSE TREE OF GENERATED PARAPHRASE
H = 4

SGCP: Syntax Guided Controlled Paraphraser
SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model

(1) SENTENCE ENCODER
how
close
are
we
to
a
real
iron
suit
?

(2) SYNTACTIC ENCODER
Sentence Encoder

EXEMPLAR SENTENCE
is it safe to access the deep web?

Syntactic Encoder

PARSE TREE OF EXEMPLAR SENTENCE
VBZ PRP ADJP S

PARSE TREE OF GENERATED PARAPHRASE
SBARQ SQ <DOT>

Similar Syntax

H = 4

(3) SYNTACTIC PARAPHRASE DECODER

Decoder

<SOS> is it possible to make a real iron

SGCP: Syntax Guided Controlled Paraphraser
SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model

1) SENTENCE ENCODER
2) SYNTACTIC ENCODER
3) SYNTACTIC PARAPHRASE DECODER

How close are we to a real iron suit?

Is it safe to access the deep web?

Exemplar Sentence

Parse Tree of Exemplar Sentence

Similar Syntax

Parse Tree of Generated Paraphrase

...
SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model
how close are we to a real iron man suit?
How close are we to a real iron man suit?
SGCP : Sentence Encoder

(1) **SENTENCE ENCODER**

```
h^X_1
how

h^X_i
close

are

we

to

a

real

iron

man

suit

?  s_t (from Decoder)
```
how close are we to a real iron man suit?
SGCP : Sentence Encoder

\[ h_i^X = \text{GRU}(h_{i-1}^X, e(x_i)) \]

\[ e_i^t = \nu^\top \tanh(W_h h_i^X + W_s s_t + b_{\text{attn}}) \]

\[ \alpha^t = \text{softmax}(e^t) \]

\[ c_t = \sum_i \alpha_i^t h_i^X \]
SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model

(1) SENTENCE ENCODER

how close are we to a real iron suit?

(2) SYNTACTIC ENCODER

is it possible to make a real iron suit?

(3) SYNTACTIC PARAPHRASE DECODER

is it possible to make a real iron suit?
SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model

1. **SENTENCE ENCODER**
   - how
   - close
   - are
   - we
   - to
   - a
   - real
   - iron
   - man
   - suit
   - ?

2. **SYNTACTIC ENCODER**
   - PARSE TREE OF EXEMPLAR SENTENCE
     - H = 4
     - SQ
     - VBZ
     - NP
     - ADJP
     - PRP
     - ADJP
     - S

3. **SYNTACTIC PARAPHRASE DECODER**
   - <SOS>
   - is
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Exemplar Sentence:
- is it safe to access the deep web?

Similar Syntax:
- Parse Tree of Exemplar Sentence
  - H = 4
  - SQ
  - VBZ
  - NP
  - ADJP
  - PRP
  - ADJP
  - S

Parse Tree of Generated Paraphrase
- H = 4
- SQ
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Constituency Parser
- <SOS>
- is
- it
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- real
- iron

(study diagram and model details for more information)
SGCP: Syntactic Encoder

**Exemplar Sentence**

Is it safe to access the deep web?

**Parse Tree of Exemplar Sentence**

- S
- VBZ
- PRP
- ADJP
- NP
- ADJP
- S

**Syntactic Encoder**

- SBARQ
- SQ
- H = 4
- DOT
- VBZ
- PRP
- ADJP
- ADJP
- S

**Constituency Parser**

- h_{VBZ}^Y
- h_{PRP}^Y
- h_{ADJP}^Y
- h_{S}^Y
- h_{<DOT>}^Y
SGCP: Syntactic Encoder

EXEMPLAR SENTENCE
is it safe to access the deep web?

(2) SYNTACTIC ENCODER

PARSE TREE OF EXEMPLAR SENTENCE

H = 4

S

SBARQ

VBZ

NP

ADJP

PRP

S

<DOT>

h_Y^v = \text{GeLU}(W_{pa} h_{pa(v)}^Y + W_v e(y_v) + b_v)

\underline{H}^Y = [h_{VBZ}^Y, h_{PRP}^Y, h_{ADJP}^Y, h_S^Y, h_{<DOT>}^Y]
**SGCP: Syntactic Encoder**

**EXEMPLAR SENTENCE**

*is it safe to access the deep web?*

**PARSE TREE OF EXEMPLAR SENTENCE**

H = 4

**SBARQ**

**SQ**

**VBZ**

**NP**

**ADJP**

**PRP**

**ADJP**

**S**

**<DOT>**

**CONSTITUENCY PARSER**

**SYNTACTIC ENCODER**

\[ h^Y_v = \text{GeLU}(W_{pa} h^Y_{pa(v)} + W_v e(y_v) + b_v) \]

\[ \mathcal{L}^Y_H = [h^Y_{VBZ}, h^Y_{PRP}, h^Y_{ADJP}, h^Y_S, h^Y_{<DOT>}] \]
is it safe to access the deep web?

\[ h^Y_v = \text{GeLU}(W_{pa}h^Y_{pa(v)} + W_v e(y_v) + b_v) \]

\[ \square^Y_H = [h^Y_{\text{VBZ}}, h^Y_{\text{PRP}}, h^Y_{\text{ADJP}}, h^Y_S, h^Y_{\text{<DOT>}}] \]
SGCP: Syntactic Encoder

EXEMPLAR SENTENCE

is it safe to access the deep web?

PARSER

CONSTITUENCY

PARSE TREE OF EXEMPLAR SENTENCE

H = 4

S

S

SQ

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ADJP

ADJP

NP

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PRP

h_v^Y = \text{GeLU}(W_{pa} h_{pa(v)}^Y + W_v e(y_v) + b_v)

\mathbb{L}_H^Y = [h_{VBZ}^Y, h_{PRP}^Y, h_{ADJP}^Y, h_s^Y, h_{<DOT>}^Y]
SGCP: Syntactic Encoder

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SGCP: Syntactic Encoder

**EXEMPLARY SENTENCE**

*is it safe to access the deep web?*

**PARSER**

**CONSTITUENCY PARSER**

**PARSE TREE OF EXEMPLAR SENTENCE**

\[ H = 4 \]

\[
\begin{align*}
    h^Y_v &= \text{GeLU}(W_{pa} h^Y_{pa(v)} + W_v e(y_v) + b_v) \\
    \downarrow H^Y &= [h^Y_{VBZ}, h^Y_{PRP}, h^Y_{ADJP}, h^Y_S, h^Y_{<DOT>}]
\end{align*}
\]
is it safe to access the deep web?

\[ h^Y_v = \text{GeLU}(W_{pa} h^Y_{pa(v)} + W_v e(y_v) + b_v) \]

\[ \downarrow_H^Y = [h^Y_{VBZ}, h^Y_{PRP}, h^Y_{ADJP}, h^Y_S, h^Y_{<DOT>} ] \]
is it safe to access the deep web?

\[ h^Y_v = \text{GeLU}(W_{pa} h^Y_{pa(v)} + W_v e(y_v) + b_v) \]

\[ \mathbb{L}^Y_H = [h^Y_{VBZ}, h^Y_{PRP}, h^Y_{ADJP}, h^Y_S, h^Y_{<DOT>} \]
SGCP: Syntactic Encoder

EXEMPLAR SENTENCE

is it safe to access the deep web?

PARSE TREE OF EXEMPLAR SENTENCE

H = 4

SBARQ

SQ

VBZ

NP

ADJP

PRP

ADJP

S

<DOT>

SYNTACTIC ENCODER

H = 4

\[ h_v^Y = \text{GeLU}(W_{pa} h_{pa(v)}^Y + W_v e(y_v) + b_v) \]

\[ \mathbb{L}_H^Y = [h_{VBZ}^Y, h_{PRP}^Y, h_{ADJP}^Y, h_S^Y, h_{<DOT>}^Y] \]
SGCP: Syntactic Encoder

\[ h_v^Y = \text{GeLU}(W_{pa}h_{pa(v)}^Y + W_v e(y_v) + b_v) \]

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is it safe to access the deep web?

\[ h_v^Y = \text{GeLU}(W_{pa} h_{pa(v)}^Y + W_v e(y_v) + b_v) \]

\[ \downarrow^Y_H = [h_{VBZ}^Y, h_{PRP}^Y, h_{ADJP}^Y, h_S^Y, h_{<DOT>}^Y] \]
What is the best language for web development?
What is the best language for web development?
Syntactic Tree to Syntactic Signalling Vector (Only during Training)

What is the best language for web development?

$H = 3; a = (1,1,0,0,0,0,0,0,1)$
What is the best language for web development?
What is the best language for web development?
Syntactic Tree to Syntactic Signalling Vector (Only during Training)

What is the best language for web development?
What is the best language for web development?

H = 2; a = (1, 1, 0, 0, 0, 0, 0, 0, 1)

H = 3; a = (1, 1, 1, 0, 0, 0, 0, 0, 1)

H = 4; a = (1, 1, 1, 0, 1, 0, 0, 1)

H = 5; a = (1, 1, 1, 1, 1, 1, 0, 1)

Syntactic Tree to Syntactic Signalling Vector (Only during Training)
SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model

(1) SENTENCE ENCODER

how close are we to a real iron suit?

(2) SYNTACTIC ENCODER

is it possible to make a real iron suit?

(3) SYNTACTIC PARAPHRASE DECODER

<SOs> is it possible to make a real iron suit?
SGCP: Syntax Guided Controlled Paraphraser

Use Syntactic Tree Structure to Guide Paraphrase Generation model
SGCP: Decoder

(3) SYNTACTIC PARAPHRASE DECODER
SGCP: Decoder

(3) SYNTACTIC PARAPHRASE DECODER
SGCP: Decoder

\[
p_t = \sigma(W_{bop}([c_t; h_t^Y; s_t; e(z_t')] + b_{bop})
\]

\[
h_{t+1}^Y = \begin{cases} 
  h_t^Y & p_t < 0.5 \\
  \text{pop}(L_H^Y) & \text{otherwise}
\end{cases}
\]
SGCP: Decoder

\[ p_t = \sigma(W_{bop}([c_t; h_t^Y; s_t; e(z'_t)]) + b_{bop}) \]

\[ h_{t+1}^Y = \begin{cases} h_t^Y & \text{if } p_t < 0.5 \\ \text{pop}(\mathbb{L}^Y_H) & \text{otherwise} \end{cases} \]

\[ \mathbb{P}(z) = \text{softmax}(W([c_t; h_t^Y; s_t; e(z'_t)]) + b) \]
SGCP Objective
SGCP Objective

\[ \mathcal{L} = -\frac{1}{T} \sum_{t=0}^{T} \left[ \log \mathbb{P}(z_t^*) + a_t \log(p_t) + (1 - a_t) \log(1 - p_t) \right] \]

- \( a_t \): Signalling vector,
- \( p_t \): Transition probability,
- \( T \): Generation Time-step,
- \( z_t^* \): Ground Truth token
Dataset Statistics
# Dataset Statistics

<table>
<thead>
<tr>
<th></th>
<th>Train*</th>
<th>Dev.</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>ParaNMT-small</td>
<td>4,92,878</td>
<td>500</td>
<td>800</td>
</tr>
<tr>
<td>QQP-Pos</td>
<td>1,37,185</td>
<td>3000</td>
<td>3000</td>
</tr>
</tbody>
</table>

* During Training: Exemplar = Reference Paraphrase
## Syntactic Granularity & SGCP-Variations

<table>
<thead>
<tr>
<th>GRANULARITY</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOURCE</strong></td>
<td>what are pure substances? what are some examples?</td>
</tr>
<tr>
<td><strong>EXEMPLAR</strong></td>
<td>what are the characteristics of the elizabethan theatre?</td>
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<td>what are pure substances?</td>
</tr>
<tr>
<td>H = 5</td>
<td>what are some of pure substances?</td>
<td>what are some of pure substances?</td>
</tr>
<tr>
<td>H = 6</td>
<td>what are some examples of pure substances?</td>
<td>what are some examples of pure substances?</td>
</tr>
<tr>
<td>H = 7</td>
<td>what are some examples of a pure substance?</td>
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</table>

**SGCP VARIATIONS**

- **SGCP-F (Full Tree)**: what are some examples of a pure substance ?
## Syntactic Granularity & SGCP-Variations

### GRANULARITY

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<tr>
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### SGCP VARIATIONS

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<tr>
<th>SGCP-F (Full Tree)</th>
<th>what are some examples of a pure substance ?</th>
</tr>
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<tbody>
<tr>
<td>SGCP-R (ROUGE)</td>
<td>what are some examples of pure substances ?</td>
</tr>
</tbody>
</table>
Fidelity
QQP-Pos Dataset
Fidelity
QQP-Pos Dataset

<table>
<thead>
<tr>
<th>Model</th>
<th>BLEU Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCPN</td>
<td>15.6</td>
</tr>
<tr>
<td>CGEN</td>
<td>34.9</td>
</tr>
<tr>
<td>SGCP-F</td>
<td>36.7</td>
</tr>
<tr>
<td>SGCP-R</td>
<td>38.0</td>
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Fidelity
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**BLEU Scores**

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**METEOR Scores**

<table>
<thead>
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<tbody>
<tr>
<td>SCPN</td>
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<tr>
<td>SGCP-R</td>
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</table>
Fidelity
QQP-Pos Dataset

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</table>

High Lexical Overlap with Reference Sentence
Fidelity
ParaNMT-small Dataset
Fidelity
ParaNMT-small Dataset

<table>
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<tr>
<th>Model</th>
<th>BLEU Scores</th>
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<tbody>
<tr>
<td>SCPN</td>
<td>6.4</td>
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<tr>
<td>CGEN</td>
<td>13.6</td>
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<tr>
<td>SGCP-F</td>
<td>15.3</td>
</tr>
<tr>
<td>SGCP-R</td>
<td>16.4</td>
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</tbody>
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Fidelity
ParaNMT-small Dataset

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<tbody>
<tr>
<td>SCPN</td>
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<tr>
<td>CGEN</td>
<td>24.8</td>
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<tr>
<td>SGCP-F</td>
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<tr>
<td>SGCP-R</td>
<td>27.2</td>
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</tbody>
</table>
Fidelity

ParaNMT-small Dataset

High Lexical Overlap with Reference Sentence
Fidelity : Paraphrase Detection Score (PDS)
Fidelity: Paraphrase Detection Score (PDS)

<table>
<thead>
<tr>
<th>Model</th>
<th>PDS: QQP-Pos</th>
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<tr>
<td>SCPN</td>
<td>27.0</td>
</tr>
<tr>
<td>CGEN</td>
<td>65.4</td>
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<tr>
<td>SGCP-F</td>
<td>75.0</td>
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<tr>
<td>SGCP-R</td>
<td>87.7</td>
</tr>
</tbody>
</table>
Fidelity: Paraphrase Detection Score (PDS)

**PDS : QQP-Pos**

- SCPN: 27.0
- CGEN: 65.4
- SGCP-F: 75.0
- SGCP-R: 87.7

**PDS : ParaNMT-small**

- SCPN: 15.4
- CGEN: 70.2
- SGCP-F: 76.6
- SGCP-R: 83.5
Fidelity: Paraphrase Detection Score (PDS)

High Model-based Semantic Scores (wrt Source Sentence)
Syntax Conformation
QQP-Pos Dataset
Syntax Conformation
QQP-Pos Dataset

Tree Edit Distance with Reference (Lower is better)

<table>
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<tr>
<th>Method</th>
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<tr>
<td>SCPN</td>
<td>9.1</td>
</tr>
<tr>
<td>CGEN</td>
<td>6.7</td>
</tr>
<tr>
<td>SGCP-F</td>
<td>4.8</td>
</tr>
<tr>
<td>SGCP-R</td>
<td>6.8</td>
</tr>
</tbody>
</table>
Syntax Conformation

QQP-Pos Dataset

Tree Edit Distance with Reference (Lower is better)

- SCPN: 9.1
- CGEN: 6.7
- SGCP-F: 4.8
- SGCP-R: 6.8

Tree Edit Distance with Exemplar (Lower is better)

- SCPN: 8.0
- CGEN: 6.0
- SGCP-F: 1.8
- SGCP-R: 5.9
Syntax Conformation
QQP-Pos Dataset

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**Syntactic Conformation is high when provided with full target syntactic signal**

<table>
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<tr>
<th>Method</th>
<th>Tree Edit Distance with Exemplar (Lower is better)</th>
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<tbody>
<tr>
<td>SCPN</td>
<td>8.0</td>
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<tr>
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</tr>
<tr>
<td>SGCP-R</td>
<td>8.7</td>
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The diagram shows the Tree Edit Distance with Reference for different models. A lower value indicates better syntax conformation.
Syntax Conformation
ParaNMT-small Dataset

Tree Edit Distance with Reference (Lower is better)

Tree Edit Distance with Exemplar (Lower is better)
Syntax Conformation
ParaNMT-small Dataset

Syntactic Conformation is high when provided with full target syntactic signal
# Syntactically Diverse Exemplar Inputs

**SOURCE:** how do i develop my career in software?

<table>
<thead>
<tr>
<th>SYNTACTIC EXEMPLAR</th>
<th>SGCP-R GENERATIONS</th>
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</thead>
<tbody>
<tr>
<td>how can i get a domain for free ?</td>
<td>how can i develop a career in software ?</td>
</tr>
<tr>
<td>what is the best way to register a company ?</td>
<td>what is the best way to develop career in software ?</td>
</tr>
<tr>
<td>what is chromosomal mutation ? what are some examples ?</td>
<td>what is a good career ? what are some of the ways to develop my career in software ?</td>
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# Syntactically Diverse Exemplar Inputs

**SOURCE:** how do I develop my career in software?

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Conclusion
Conclusion

Problem

Syntactically Controlled Generation

While preserving semantics
Conclusion

**Problem**

Syntactically Controlled Generation

While preserving semantics

**Method**

**SGCP**

Guiding Decoder Using Syntactictic Signals
Conclusion

Problem
Syntactically Controlled Generation
While preserving semantics

Method
SGCP
Guiding Decoder Using Syntactic Signals

Future Work
Target Syntax Compatibility
Data Augmentation Using Syntactic Paraphrasing
Code

https://github.com/malllabiisc/SGCP
Code

https://github.com/malllabiisc/SGCP

Acknowledgement
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ashutosh@iisc.ac.in, kabirahuja2431@gmail.com, raghuram.4350@gmail.com, ppt@iisc.ac.in
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Thank you