Sentence Compression for Arbitrary Languages via Multilingual Pivoting

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Abstract

In this paper we advocate the use of bilingual corpora which are abundantly available for training sentence compression models. Our approach borrows much of its machinery from neural machine translation and leverages bilingual pivoting: compressions are obtained by translating a source string into a foreign language and then back-translating it into the source while controlling the translation length. Our model can be trained for any language as long as a bilingual corpus is available and performs arbitrary rewrites without access to compression specific data. We release\(^1\) MOSS, a new parallel Multilingual Compression dataset for English, German, and French which can be used to evaluate compression models across languages and genres.

1 Introduction

Sentence compression aims to produce a summary of a single sentence that retains the most important information while preserving its fluency. The task has attracted much attention due to its potential for applications such as text summarization (Jing, 2000; Madnani et al., 2007; Woodsend and Lapata, 2010; Berg-Kirkpatrick et al., 2011), subtitle generation (Vandeghinste and Pan, 2004; Luotilahti and Ginter, 2015), and the display of text on small-screens (Corston-Oliver, 2001).

The bulk of research on sentence compression has focused on a simplification of the task involving exclusively word deletion (Knight and Marcu, 2002; Riezler et al., 2003; Turner and Charniak, 2005; McDonald, 2006; Clarke and Lapata, 2008; Cohn and Lapata, 2009), whereas a few approaches view sentence compression as a more general text rewriting problem (Galley and McKeown, 2007; Woodsend and Lapata, 2010; Cohn and Lapata, 2013). Irrespective of how the compression task is formulated, most previous work relies on syntactic information such as parse trees to help decide what to delete from a sentence or which rules to learn in order to rewrite a sentence using less words. More recently, there has been much interest in applying neural network models to natural language generation tasks, including sentence compression (Rush et al., 2015; Filippova et al., 2015; Chopra et al., 2016; Kikuchi et al., 2016). Filippova et al. (2015) focus on deletion-based sentence compression which they model as a sequence labeling problem using a recurrent neural network with long short-term memory units (LSTM; Hochreiter and Schmidhuber 1997). Rush et al. (2015) capture the full gamut of rewrite operations drawing insights from encoder-decoder models recently proposed for machine translation (Bahdanau et al., 2015).

Neural network-based approaches are data-driven, relying on the ability of recurrent architectures to learn continuous features without recourse to preprocessing tools or syntactic information (e.g., part-of-speech tags, parse trees). In order to achieve good performance, they require large amounts of training data, in the region of millions of long-short sentence pairs.\(^2\) Existing compression datasets are several orders of magnitude smaller. For example, the Ziff-Davis corpus (Knight and Marcu, 2002) contains 1,067 sentences and originated from a collection of news articles on computer products. Clarke and Lapata (2008) create two manual corpora sampled from written (1,433 sentences) and spoken sources (1,370 sentences). Cohn and Lapata (2013) elicit manual compressions for 625 sentences taken from newspaper articles. More recently, Toutanova et al. (2016) crowdsource a larger corpus which contains manual compressions for 625 sentences taken from newspaper articles. More recently, Toutanova et al. (2016) crowdsource a larger corpus which contains manual compressions for 625 sentences taken from newspaper articles. More recently, Toutanova et al. (2016) crowdsource a larger corpus which contains manual compressions for single and multiple sentences (about 26,000 pairs of source and compressed texts).

Since large scale compression datasets do not occur naturally, they must be somehow approx-\(^3\)

\(^{1}\)Publicly available for download at https://github.com/Jmallins/MOSS

imated, e.g., by pairing headlines with the first sentence of a news article (Filippova and Altun, 2013; Rush et al., 2015). As a result, the training corpus construction process must be repeated and reconfigured for new languages and domains (e.g., many headline-first sentence pairs are spurious and need to be filtered using language and domain specific heuristics). And although it may be easy to automatically obtain large scale training data in the news domain, it is not clear how such data can be sourced for many other genres with different writing conventions.

Our work addresses the paucity of data for sentence compression models. We argue that multilingual corpora are a rich source for learning a variety of rewrite rules across languages and that existing neural machine translation (NMT) models (Sutskever et al. 2014; Bahdanau et al. 2015) can be easily adapted to the compression task through bilingual pivoting (Mallinson et al., 2017) coupled with methods which decode the output sequence to a desired length (e.g., subject to language and genre requirements).

We obtain compressions by translating a source string into a foreign language and then back-translating it into the source while controlling the translation length (Kikuchi et al., 2016). Our model can be trained for any language as long as a bilingual corpus is available, and can perform arbitrary rewrites while taking advantage of multiple pivots if these exist. We also demonstrate that models trained on multilingual data perform well out-of-domain.

Although our approach does not employ compression corpora for training, for evaluation purposes, we create MOSS, a new Multilingual Compression dataset for English, French, and German. MOSS is a parallel corpus containing documents from the European parliament proceedings, TED talks, news commentaries, and the EU bookshop. Each document is written in English, French, and German, and compressed by native speakers of the respective language. who process a document at a time. We obtain five compressions per document leading to 2,000 long-short sentence pairs per language. Like previous related resources (Clarke and Lapata, 2008; Cohn and Lapata, 2013; de Loupy et al., 2010) our corpus is curated manually, however it differs from Toutanova et al. (2016) in that it contains compressions for individual sentences, not documents.

There has been relatively little interest in compressing languages other than English. A few models have been proposed for Japanese (Hori and Furui, 2004; Hirao et al., 2009; Harashima and Kurohashi, 2012), including a neural network model (Hasegawa et al., 2017) which repurposes Filippova and Altun’s (2013) data construction method for Japanese. There is a compression corpus available for French (de Loupy et al., 2010), however, we are not aware of any modeling work on this language. Overall, there are no standardized datasets in languages other than English, either for training or testing.

Our contributions in this work are three-fold: a novel application of bilingual pivoting to sentence compression; corroborated by empirical results showing that our model scales across languages and text genres without additional supervision over and above what is available in the bilingual parallel data; and the release of a multilingual, multi-reference compression corpus which can be effectively used to gain insight in the compression task and facilitate further research in compression modeling.

2 Pivot-based Neural Compression

In our pivot-based sentence compression model an input sequence is first translated into a foreign language, and then back into the source language. Unlike previous paraphrasing pivoting models (Mallinson et al., 2017), we parameterize our translation models with a length feature, which allows us to produce compressed output. We define two models, performing compression in one step or alternatively in two steps which affords more flexibility in model output.

2.1 NMT Background

In the neural encoder-decoder framework for MT (Bahdanau et al., 2015; Sutskever et al., 2014), an encoder takes in a source position $i$ of length $T_i$ and the decoder generates a target sequence $(y_1, ..., y_{T_y})$ of length $T_y$. Let $h_i$ be the hidden state of the source symbol at position $i$, obtained by concatenating the forward and backward encoder RNN hidden states, $h_i = [\overrightarrow{h_i}; \overleftarrow{h_i}]$. We deviate from previous work (Bahdanau et al., 2015; Sutskever et al., 2014) in that we initialize the decoder with the average of the hidden states, following Sennrich et al. (2017):

$$s_0 = \tanh\left(W_{\text{init}} \sum_{i=1}^{T_x} \frac{h_i}{T_x}\right)$$

where $W_{\text{init}}$ is a learnt parameter. Our decoder is a conditional recurrent neural network, specifically
a gated recurrent unit (GRU, Cho et al., 2014) with
attention, which we denote as cGRUatt. cGRUatt
takes as input the previous hidden state $s_{j-1}$, the
source annotations $C = h_1, ..., h_T$, and the pre-
viously decoded symbol $y_{j-1}$ in order to update its
hidden state $s_j$, which is used to decode symbol $y_j$
at position $j$:

$$s_j = cGRUatt(s_{j-1}, y_{j-1}, C)$$  \hspace{1cm} (2)

$cGRUatt$ consists of three components. The first
combines the previously decoded symbol $y_{j-1}$ and
the previous hidden state $s_{j-1}$ to generate an inter-
mEDIATE representation $s'_j$. The attention mech-
anism, $ATT$, inputs the entire context set $C$ along
with intermediate hidden state $s'_j$ in order to com-
pute the context vector $c_j$:

$$c_j = ATT(C, s'_j) = \sum_i T_i \alpha_{ij} h_i$$  \hspace{1cm} (3)

$$\alpha_{ij} = \frac{\exp(e_{ij})}{\sum_{k=1}^{T_i} \exp(e_{kj})}$$  \hspace{1cm} (4)

$$e_{ij} = f(s'_j, h_i)$$  \hspace{1cm} (5)

Where $\alpha_{ij}$ is the normalized alignment weight be-
tween the source symbol at position $i$ and the
target symbol at position $j$, and $f$ is a feedforward
neural network.

Finally, we generate $s_j$, the hidden state of
$cGRUatt$, by using the intermediate representa-
tion $s'_j$ and the context vector $c_j$. Given $s_j$, $y_{j-1}$,
and $c_j$ the output probability $P(y_j | s_j, y_{j-1}, c_j)$ is
computed using a feedforward neural network with
a softmax activation. We define the proba-
bility of sequence $y$ as:

$$P(y | x; \theta) = \prod_{j=1}^{T_y} P(y_j | s_j, y_{j-1}, c_j)$$  \hspace{1cm} (6)

2.2 Length Control

To be able to produce compressed sentences, we
parameterize our model with a length vector which
allows to control the output length. Our approach
is similar to the LenInit model of Kikuchi et al.
(2016), however we use a GRU instead of an
LSTM. The hidden state of the decoder consists of
the average of the encoder’s hidden states but
also a length vector $LV$, a learnt parameter, which
is scaled by the desired target length $T_y$. We there-
fore rewrite Equation (1) as follows:

$$s'_0 = \tanh(W_{init} \left( \frac{\sum_{i=1}^{T_i} h_i}{T_x} \cdot LV \cdot T_y \right))$$  \hspace{1cm} (7)

As such we now define our model as:

$$P(y | x, T_y; \theta)$$  \hspace{1cm} (8)

During training, the target length is set to $T_y = T_x$. However, at test time, the target length generally
varies according to the domain, genres, and lan-
guage at hand. We determine the target length ex-
perimentally based on a small validation set.

2.3 Pivoting

Pivoting is often used in machine translation to
overcome the shortage of parallel data, i.e., when
there is no translation path from the source lan-
guage to the target by taking advantage of paths
through an intermediate language. The idea dates
back at least to Kay (1997), who observed that am-
biguities in translating from one language onto an-
other may be resolved if a translation into some
third language is available, and has met with suc-
cess in phrase-based SMT (Wu and Wang, 2007;
Utiyama and Isahara, 2007) and more recently in
neural MT systems (Firat et al., 2016).

We use pivoting to provide a path from a source
English sentence, via an intermediate foreign lan-
guage, to English in a compressed form. We pro-
pose to extend Mallinson et al.’s (2017) approach
to multi-pivoting, where a sentence $x$ is translated
to $K$-best foreign pivots, $F_k = \{f_1, ..., f_K\}$. The
probability of generating compression $y = y_1 \ldots y_{T_y}$
is decomposed as:

$$P(y | x) = \sum_{f \in F} P(y | f; \theta) \cdot P(f | x; \theta)$$  \hspace{1cm} (9)

Which we approximate as the tokenwise
weighted average of the pivots:

$$P(y | x) \approx \prod_{j=1}^{T_y} \sum_{f \in F} P(y_j | y_{<j}, f) P(f | x)$$  \hspace{1cm} (10)

Where $y_{<j} = y_1 \ldots y_{j-1}$. To ensure a probability
distribution, we normalize the K-best list $F_k$, such
that the translation probabilities sum to one.

We use beam search to decode tokens by condi-
tioning on multiple pivoting sentences. The results
with the best decoding scores are considered can-
didate compressions.

To ensure the model produces compressed output,
we extend the pivoting approach in two ways. In
single step compression, one of the translation
models is parameterized with length information:

$$P(y | x, T_y; \theta) \approx \sum_{f \in F} P(y | f, T_y; \theta) \cdot P(f | x; \theta)$$
Figure 1: Histograms of output lengths at three compression rates (CR) compared to a vanilla encoder-decoder system which does not manipulate output length. German is used as pivot for English, and English as pivot for French and German.

In dual-step compression, we parameterize both translation models with length information:

\[ P(y|x, T_y', T_y'') \approx \sum_{f} P(y|f, T_y'; \theta) \cdot P(f|x, T_y''; \theta) \]

We find that dual-compression performs better when the system is expected to drastically compress the source sentence (e.g., in a headline generation task). Imposing a high compression ratio from the start tends to produce unintelligible text. The model attempts to reduce the length of the source at all costs, even at the expense of being semantically faithful to the input. Performing two moderate compressions in succession reduces both length and content conservatively and as a result produces more meaningful text.

In Figure 1 we illustrate how the pivot-based model sketched above can successfully control the output of the generated compressions. We show the output of a single-step compression model on three languages initialized with varying compression rates\(^3\) (see Section 4 for details on how the models were trained and tested). The compression rate (CR) is used to determine length parameter of equation 8:

\[ T_y' = T_x \cdot CR \]  

The figure shows how the output length varies compared to a vanilla encoder-decoder system which uses pivoting to backtranslate the source language (Mallinson et al., 2017). We can see that the majority of sentences are generated with length close to the desired compression rate.

3 The MOSS Dataset

For evaluation purposes, we created a multilingual sentence compression corpus in English, German, and French. The corpus was collated from existing document and sentence aligned multilingual datasets which vary both in terms of topic and genre. We sampled five documents each from:

1. Europarl, the European Parliament Proceedings Parallel Corpus (Koehn, 2005), has been used extensively in machine translation research; it contains the minutes of the European parliament and is a spoken corpus of formulaic nature; speakers take part in debating various issues concerning EU policy (e.g., taxation, environment).

2. The TED parallel Corpus (Cettolo et al., 2012) contains transcripts in multiple languages of short talks devoted to spreading powerful ideas on a variety of topics ranging from science to business and global issues.

3. The EU bookshop corpus (Skadiňš et al., 2014) contains publications from European institutions covering a variety of topics such as refugees, gender equality, and travel.

4. The News Commentary Parallel Corpus contains articles downloaded from Project Syndicate, an international media organization that publishes commentary on global topics (e.g., economics, world affairs).

We obtained compressions using the Crowdflower platform. Crowdworkers were given instructions that explained the task and defined sentence compression with the aid of examples. They were asked to compress while preserving the most important information, ensuring the sentences remained grammatical and meaning preserving. Annotators were encouraged to use any rewriting operations that seemed appropriate, e.g., to delete words, add new words, substitute them, or reorder...
On the very day that the earthquake struck, the European Council asked the High Representative and the Commission to mobilise all appropriate assistance. Assistance was mobilized on the very day of the earthquake.

We're at a tipping point in human history, a species poised between gaining the stars and losing the planet we call home. We’re at tipping point in human history, poised between gaining the stars and losing the Earth.

Surveys undertaken by the World Bank in developing countries show that when poor people are asked to name the three most important concerns they face good health is always mentioned.

World Bank surveys in developing countries show poor people always name good health as an important concern.

<table>
<thead>
<tr>
<th>English</th>
<th>French</th>
<th>German</th>
</tr>
</thead>
<tbody>
<tr>
<td>On the very day that the earthquake struck, the European Council asked the High Representative and the Commission to mobilise all appropriate assistance. Assistance was mobilized on the very day of the earthquake.</td>
<td>Le jour même du tremblement de terre, le Conseil européen a demandé à la haute représentante et à la Commission de mobiliser toute l’aide appropriée.</td>
<td>Am gleichen Tag, an dem das Erdbeben ausbrach, ersuchte der Europäische Rat die Hohe Vertreterin und die Kommission um die Mobilisierung aller angemessenen Hilfe. Europa erbrachte Hilfe noch am selben Tag.</td>
</tr>
<tr>
<td>We’re at a tipping point in human history, a species poised between gaining the stars and losing the planet we call home.</td>
<td>L’histoire humaine est à un tournant. Notre espèce hésite à toucher les étoiles ou à perdre la planète qui est la sienne. L’humanité est à un tournant. Notre espèce a envie des étoiles ou à perdre sa planète.</td>
<td>Wir stehen vor einem historischen Wendepunkt: zwischen dem Griff nach den Sternen und dem Verlust unseres Heimatplaneten. Wir sind vor einem historischen Wendepunkt: zwischen dem Griff nach Sternen und Verlust unseres Planeten.</td>
</tr>
<tr>
<td>Surveys undertaken by the World Bank in developing countries show that when poor people are asked to name the three most important concerns they face good health is always mentioned.</td>
<td>Les enquêtes menées par la Banque mondiale dans les pays en développement montrent que, quand on demande aux populations pauvres de nommer les trois défis les plus importants qu’ils rencontrent, leur “bonne santé” fait toujours partie de cette liste. Quand on demande aux populations pauvres de nommer les trois défis les plus importants qu’ils rencontrent, leur “bonne santé” fait toujours partie de la liste.</td>
<td>Umfragen der Weltbank in Entwicklungsländern zeigen, wenn man Arme nach den drei wichtigsten Anliegen fragt, die sie beschäftigen, wird “Gesundheit” immer genannt. Umfragen in Entwicklungsländern zeigen, dass bei Armen das wichtigste Anliegen Gesundheit ist.</td>
</tr>
</tbody>
</table>

Table 1: Examples of crowdsourced compressions (in italics) from the MOSS corpus. Sentences shown (in order of appearance) from Europarl, TED, and News Commentary corpora.

4 Experimental Setup

Neural Machine Translation Training Nematus (Sennrich et al., 2017) was used as the machine translation system for all our experiments. We generally used the default settings and training procedures as specified within Nematus. All networks have a hidden layer size of 1,000, and an embedding layer size of 512. In addition, layer normalization (Ba et al., 2016) was used. During training, we used ADAM (Kingma and Ba, 2014), a minibatch size of 80, and the training set was reshuffled between epochs. We also employed early stopping.

We used up to four encoder-decoder NMT models in our experiments (BLEU scores\(^4\) shown in parentheses): English→French (27.03), French→English (29.14), English→German (29.34), and German→English (26.60). German training/test data was taken from the WMT16

\(^4\)BLEU scores were calculated using mteval-v13a.pl
We compared our model against ABS, a sequence-to-sequence\footnote{We used our own implementation of ABS and LenInit which on DUC-2004 obtained ROUGE scores similar to those published in Rush et al. (2015) and Kikuchi et al. (2016).}\footnote{We add a begin-of-sentence marker at the start of the candidate and reference sentences}\footnote{5} sequence attention-based model, developed by Rush et al. (2015). This model was trained on a monolingual dataset extracted from the Annotated English Gigaword corpus (Napoles et al., 2011). The dataset consists of approximately 4 million pairs of the first sentence from each source document and its headline. We also trained LenInit (Kikuchi et al., 2016) on the same corpus which is conceptually similar to ABS but additionally controls the output length using a length embedding vector (as described in Section 2.2).\footnote{We used our own implementation of ABS and LenInit which on DUC-2004 obtained ROUGE scores similar to those published in Rush et al. (2015) and Kikuchi et al. (2016).} Unfortunately, we could not train these models for French or German, since there are no monolingual sentence compression datasets available at a similar scale. An obvious workaround is to translate Gigaword to French and German and then train compression models on the translated data. As the quality of the translation is relatively poor, we also translated German or French into English, compressed it with ABS and LenInit trained on the Gigaword corpus, and then translated the compressions back to French or German.

Finally, we include a prefix ($P$) rollout which does not perform any rewriting but simply truncates the source sentence so that it matches the compression ratio of the validation set.

### 5 Results

**Moss Evaluation** We assessed model performance using three automatic metrics which represent different aspects of the compression task and have been found to correlate well with human judgments (Toutanova et al., 2016; Clarke and Lapata, 2006). These include a recall metric based on skip bi-grams, any pair of words in a sequence allowing for gaps of size four\footnote{6} (RS-R); a recall metric based on bi-grams of dependency tree triples (D2-R); and bi-gram ROUGE (R2-F1). We used the Stanford neural network parser (Chen and Manning, 2014) to obtain dependency triples.

Table 3(a) reports results on English with a model which controls the output length ($L$) and uses either a single pivot (SP; $K = 1$) or multiple pivots (MP; $K = 10$). We experimented with French (fr) or German (de) as pivot languages. All pivot-based models perform compression in a single step (see Section 2.3). Dual-step compression obtained inferior results which we omit for the sake of brevity.

<table>
<thead>
<tr>
<th>Language</th>
<th>SL</th>
<th>TL</th>
<th>CR</th>
<th>TER</th>
<th>Ins</th>
<th>Del</th>
<th>Sub</th>
<th>Shft</th>
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</thead>
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<tr>
<td>English</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TED</td>
<td>20.52</td>
<td>16.12</td>
<td>0.78</td>
<td>0.32</td>
<td>0.11</td>
<td>4.50</td>
<td>1.54</td>
<td>0.38</td>
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<tr>
<td>News</td>
<td>20.52</td>
<td>16.12</td>
<td>0.78</td>
<td>0.32</td>
<td>0.11</td>
<td>4.50</td>
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<tr>
<td>Books</td>
<td>20.52</td>
<td>16.12</td>
<td>0.78</td>
<td>0.32</td>
<td>0.11</td>
<td>4.50</td>
<td>1.54</td>
<td>0.38</td>
</tr>
<tr>
<td>All</td>
<td>19.41</td>
<td>13.99</td>
<td>0.73</td>
<td>0.37</td>
<td>0.10</td>
<td>5.78</td>
<td>1.55</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Table 2: Moss statistics across corpora and languages: length of source (SL) and target sentence (TL), compression rate (CR), TER scores, and number of insertions (Ins), deletions (Del), substitutions (Sub), and shifts (Shft).
Table 3: Automatic evaluation on MOSS; S/M: single/multiple pivot models; \(L\): length parameter; pivot languages: English (en), French (fr), German (de); ABS (Rush et al., 2015) and LenInit (Kituchi et al., 2016) are sequence-to-sequence models trained on Gigaword; Gold is inter-annotator agreement.

<table>
<thead>
<tr>
<th>English</th>
<th>RS-R</th>
<th>D2-R</th>
<th>R2-F1</th>
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<tbody>
<tr>
<td>Pix</td>
<td>45.38</td>
<td>47.37</td>
<td>33.67</td>
</tr>
<tr>
<td>ABS</td>
<td>18.29</td>
<td>23.55</td>
<td>15.60</td>
</tr>
<tr>
<td>LenInit</td>
<td>17.90</td>
<td>19.64</td>
<td>11.18</td>
</tr>
<tr>
<td>(SP_{en})</td>
<td>34.60</td>
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<tr>
<td>(SP_{fr})</td>
<td>27.42</td>
<td>32.34</td>
<td>19.29</td>
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<tr>
<td>(MP_{en})</td>
<td>28.71</td>
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<tr>
<td>(MP_{fr})</td>
<td>20.54</td>
<td>27.50</td>
<td>13.89</td>
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<tr>
<td>Gold</td>
<td>76.60</td>
<td>71.68</td>
<td>42.89</td>
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<table>
<thead>
<tr>
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<th>R2-F1</th>
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<tr>
<td>Pix</td>
<td>60.33</td>
<td>62.44</td>
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<tr>
<td>ABS</td>
<td>13.84</td>
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<td>LenInit</td>
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<td>13.17</td>
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<tr>
<td>(MP_{fr})</td>
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<td>46.17</td>
<td>35.07</td>
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<tr>
<td>Gold</td>
<td>74.42</td>
<td>80.00</td>
<td>52.13</td>
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</table>

<table>
<thead>
<tr>
<th>German</th>
<th>RS-R</th>
<th>D2-R</th>
<th>R2-F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pix</td>
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<td>50.78</td>
<td>45.84</td>
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<tr>
<td>ABS</td>
<td>5.72</td>
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<td>5.21</td>
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<tr>
<td>LenInit</td>
<td>9.43</td>
<td>14.78</td>
<td>6.79</td>
</tr>
<tr>
<td>(SP_{en})</td>
<td>4.91</td>
<td>11.77</td>
<td>2.87</td>
</tr>
<tr>
<td>(SP_{fr})</td>
<td>13.19</td>
<td>18.67</td>
<td>7.65</td>
</tr>
<tr>
<td>(MP_{en})</td>
<td>23.62</td>
<td>29.13</td>
<td>17.36</td>
</tr>
<tr>
<td>(MP_{fr})</td>
<td>38.19</td>
<td>38.54</td>
<td>31.15</td>
</tr>
<tr>
<td>Gold</td>
<td>76.01</td>
<td>77.48</td>
<td>48.36</td>
</tr>
</tbody>
</table>

Table 4: System output for the example source sentences in Table 1.

<table>
<thead>
<tr>
<th>English</th>
<th>French</th>
<th>German</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Le Conseil Européen demande une aide pour les victimes du tremblement de terre.</td>
<td>Européischer Rat sucht Hilfe für Opfer.</td>
</tr>
<tr>
<td>SP</td>
<td>The European Council called on the High Representative and the Commission to mobilise all appropriate assistance.</td>
<td>Am selben Tag forderte der Europäische Rat die Hohe Vertreterin und die Kommission auf, jede Hilfe.</td>
</tr>
<tr>
<td>SP</td>
<td>We are at a turning point in human history and losing the planet we call home.</td>
<td>Wenn man die Armen nach den drei Hauptanliegen fragt, werden sie gefordert.</td>
</tr>
<tr>
<td>ABS</td>
<td>Poor people ask to name the three most important concerns.</td>
<td>Les enquêtes de la Banque mondiale révèlent que la santé fait toujours partie de la liste.</td>
</tr>
<tr>
<td>SP</td>
<td>Polls conducted by the World Bank show that when poor people are asked to mention the three main concerns.</td>
<td>Les enquêtes menées par la Banque mondiale dans les pays en développement montrent que, lorsqu’on demande aux pauvres de nommer les trois plus grands échs.</td>
</tr>
</tbody>
</table>

Table 5: Mean ratings elicited by humans on MOSS; Avg is the average rating of grammaticality and importance.

<table>
<thead>
<tr>
<th>Models</th>
<th>English</th>
<th>French</th>
<th>German</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pix</td>
<td>2.72</td>
<td>2.98</td>
<td>2.85</td>
</tr>
<tr>
<td>LenInit</td>
<td>2.51</td>
<td>3.00</td>
<td>2.75</td>
</tr>
<tr>
<td>(SP_{en})</td>
<td>3.27</td>
<td>3.69</td>
<td>3.48</td>
</tr>
<tr>
<td>(MP_{en})</td>
<td>3.47</td>
<td>3.80</td>
<td>3.63</td>
</tr>
<tr>
<td>(SP_{fr})</td>
<td>2.73</td>
<td>2.80</td>
<td>2.80</td>
</tr>
<tr>
<td>(MP_{fr})</td>
<td>2.10</td>
<td>2.62</td>
<td>2.22</td>
</tr>
<tr>
<td>(MP_{en})</td>
<td>3.17</td>
<td>3.73</td>
<td>3.87</td>
</tr>
<tr>
<td>(MP_{fr})</td>
<td>4.05</td>
<td>4.14</td>
<td>4.10</td>
</tr>
<tr>
<td>(SP_{fr})</td>
<td>3.00</td>
<td>3.54</td>
<td>3.59</td>
</tr>
<tr>
<td>(MP_{en})</td>
<td>3.97</td>
<td>4.26</td>
<td>4.10</td>
</tr>
<tr>
<td>(MP_{fr})</td>
<td>3.87</td>
<td>3.87</td>
<td>3.59</td>
</tr>
</tbody>
</table>

these models are tested on out of domain data with different vocabulary and writing conventions; MOSS does not contain any newspaper articles. Unfortunately, it is not possible to train ABS and LenInit on in-domain data as compression data only exists for the headlines-first sentences pairs. As an upper bound, we also report how well humans agree with each other, treating one (randomly selected) reference as system output and computing how it agrees with the rest (row Gold in Table 3). All models lag significantly behind human performance on this task.

Tables 3(b) and 3(c) report results on French and German, respectively. For these languages, we obtained best results with English as pivot, using a single-step compression model. ABS and LenInit perform poorly when trained directly on translations of Gigaword into French and German; their performance improves considerably when they are trained on the Gigaword and used to compress English translations of French or German (ABS\(_{en}\), LenInit\(_{en}\)). Again, we observe that our models (\(SP_{en}\), \(MP_{en}\)) outperform the comparison systems across all metrics and that using a single pivot yields better compressions. Example compressions are given in Table 4 where we show output produced by ABS and SP for each language (see the supplementary material for more examples). Finally, notice that automatic scores for the prefix baseline across languages are misleadingly high, since it simply repeats the source sentence up to a fixed length without performing any rewriting.
Table 6: Statistics of model output (SPₜ) on MOSS (aggregated across domains): length of source (SL) and target (TL), compression rate (CR), TER scores, and number of insertions (Ins), deletions (Del), substitutions (Sub), and shifts (Shft).

We also elicited human judgments through the Crowdflower platform. We asked crowdworkers to rate the grammaticality of the target compressions and whether they preserved the most important information from the source. In both cases, they used a five-point rating scale where a high number indicates better performance. We randomly selected 25 sentences from each corpus from the test portion of MOSS, i.e., 100 long-short sentence pairs per language. We compared compressions generated by our model (SPₜ), with ABS models for the three languages, the prefix baseline, and (randomly selected) gold-standard reference (Ref) compressions from MOSS. All systems used the length parameter to allow comparisons with approximately the same compression rates. We collected five ratings per compression. Our results are summarized in Table 5. We show mean ratings for grammaticality (Gram), importance (Imp) and their combination (column Avg). Across languages our model (SPₜ) significantly (p < 0.05) outperforms comparison systems (Pfix, ABS) on both dimensions of grammaticality and importance (significance tests were performed using a student t-test). All systems are significantly worse (p < 0.05) than the human reference compressions.

Finally, in Table 6 we analyze the output of our best model (SPₜ) using the same statistics we applied to the human compressions (see Table 2). As can be seen, the model generally compresses more aggressively and applies more edits than the crowdworkers (both compression rates and TER scores are higher for all three languages). Although the rate of insertions and deletions is similar to humans, substitutions and shifts happen to a greater extent for our model, indicating that it performs a good amount of paraphrasing.

**DUC-2004 Evaluation** Besides MOSS, we evaluated our model on the benchmark DUC-2004 task-1 dataset. In this task, the aim is to create a very short summary (75 bytes) for a document. The evaluation set consists of 500 source documents (from the New York Times and Associated Press Wire services) each paired with four human-written (reference) summaries. We follow previous work (Rush et al., 2015; Chopra et al., 2016) in compressing the first sentence of the document and presenting this as the summary. To make the evaluation unbiased to length, the output of all systems is cut-off after 75-characters and no bonus is given for shorter summaries.

Our results are shown in Table 7. To compare with existing methods, we also report ROUGE (Lin, 2004) unigram and bigram overlap (Lin, 2004) and the longest common subsequence (ROUGE-L). We employed a dual step compression model (see Section 2) as preliminary experiments showed that it was superior to single-stage variants. We compared single and multiple pivot models against existing ABS and ABS+ (Rush et al., 2015), two encoder-decoder models trained on the English Gigaword. ABS+ applies minimum error rate (MERT) training as a copying mechanism. LenEmb and LenInit include a length parameter (Kikuchi et al., 2016), whereas RAS uses a specialized recurrent neural network architecture (Elman, 1990). We also report how well DUC-2004 abstractors agree with each other (row Gold in Table 7). Example compressions are given in Table 8, where we show output produced by SPₚn and a corresponding human reference (see the supplementary material for further examples).

Using automatic metrics we see that our model generally performs worse compared to these sys-

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7 Our ABS implementation obtains R1-R 25.03, R2-R 8.40, and RL-R: 22.35
8 Our LenInit implementation obtains R1-R 29.26, R2-R 9.56, and RL-R 25.70
9 We used ROUGE version 1.5.5 with the original DUC-2004 ROUGE parameters.

King Norodom Sihanouk has declined requests to chair a summit of Cambodia’s top political leaders, saying the meeting would not bring any progress in deadlocked negotiations to form a government. SP, de:

King Norodom Sihanouk has refused to chair Cambodia summit.

Cambodia’s ruling party responded Tuesday to criticisms of its leader in the U.S. Congress with a lengthy defense of strongman Hun Sen’s human rights record. SP, de:

Cambodia’s ruling party responded Tuesday to criticism of its leader in the US.

The Swiss government has ordered no investigation of possible bank accounts belonging to former Chilean dictator Augusto Pinochet, a spokesman said Wednesday. SP, de:

Swiss government ordered no inquiry into possible bank accounts of former Chilean dictator Augusto.

Table 8: System output for DUC 2004.

<table>
<thead>
<tr>
<th>Models</th>
<th>Gram</th>
<th>Imp</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pfix</td>
<td>3.03</td>
<td>2.93</td>
<td>2.98</td>
</tr>
<tr>
<td>SP, de</td>
<td>3.37</td>
<td>3.22</td>
<td>3.29</td>
</tr>
<tr>
<td>Topiary</td>
<td>3.05</td>
<td>3.15</td>
<td>3.10</td>
</tr>
<tr>
<td>ABS+</td>
<td>3.67</td>
<td>3.23</td>
<td>3.45</td>
</tr>
<tr>
<td>LenEmb</td>
<td>3.14</td>
<td>3.08</td>
<td>3.09</td>
</tr>
<tr>
<td>Ref</td>
<td>3.62</td>
<td>3.27</td>
<td>3.45</td>
</tr>
</tbody>
</table>

Table 9: Mean ratings elicited by humans on DUC-2004; Avg is the average rating of grammaticality and importance.

Topiary, and LenEmb are significantly worse than Gold; $p < 0.05$. In terms of importance, pairwise differences between systems and the gold standard are not significant. Overall, we observe that SP, de performs comparably to ABS+ even though it was not trained on any compression specific data. Inspection of system output reveals that our model performs more paraphrasing than comparison systems (a conclusion also confirmed by the statistics in Table 6).

6 Conclusions

In this paper we have shown that multilingual corpora can be used to bootstrap compression models across languages and text genres. Our approach adapts existing neural machine translation machinery to the compression task coupled with methods which decode the output to a desired length. An interesting direction for future work would be to train our model using reinforcement learning (Ranzato et al., 2016; Zhang and Lapata, 2017) in order to control the compression output more directly. Moreover, although we do not use any direct supervision in our experiments, it would be interesting to incorporate it as a means of domain adaptation (Cheng et al., 2016).

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