

# Round Trip Loss for Machine Translation

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## Abstract

We augment a machine translation system with a round-trip loss to encourage the system to generate translations that, when translated back into the source language, retain much of the original structure. While our experiments show that incorporating the proposed loss has little to no effect on the BLEU scores of the obtained translations, we present evidence that the proposed loss improves the semantic correspondence between source sequence and predicted translation, an effect that is not fully captured by the BLEU score.

**Key Words:** Cycle consistency loss; deep learning; natural language understanding; machine translation; round-trip loss.

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# 1 Introduction

Machine translation is an important task within the field of natural language understanding. Consequently, a variety of models have been proposed for solving it. One of the first truly successful models was the sequence-to-sequence (seq2seq) model of Sutskever et al. (2014), while the current state of the art builds upon the *Transformer* architecture introduced by Vaswani et al. (2017). At a high level, both the seq2seq and the Transformer architectures are comprised of an encoder and decoder; the encoder learns an internal representation of the source sentence, and the decoder decodes it into the target language. For these models to work, the internal representation must capture the semantic meaning of the source sentence.

Irrespective of the architecture, these models are typically trained with the cross-entropy loss between the ground truth and predicted sentences, usually with teacher forcing. Here, we propose to add a round-trip penalty to the loss function of the model. The idea is that instead of training a single model to translate from a source language  $\mathcal{S}$  to a target language  $\mathcal{T}$ , one trains two models (of identical structure), one mapping  $\mathcal{S} \mapsto \mathcal{T}$  and one mapping  $\mathcal{T} \mapsto \mathcal{S}$ . In this paper, we rely on the Transformer architecture of Vaswani et al. (2017), but the idea applies to any encoder-decoder architecture.<sup>1</sup> The two models are, at first, trained independently and in parallel, by feeding in the same batches of sentence pairs. After  $\tau$  epochs, the models are then trained jointly, using as loss a sum of four cross-entropy terms, viz.,

$$\mathcal{L} = CE(s, \hat{s}) + CE(t, \hat{t}) + \lambda (CE(s, \tilde{s}) + CE(t, \tilde{t})). \quad (1)$$

Here,  $s \in \mathcal{S}$  is the ground truth sentence in the first language,  $t \in \mathcal{T}$  is the corresponding ground truth in the second language,  $\hat{s} \in \mathcal{S}$  and  $\hat{t} \in \mathcal{T}$  are the respective translations of  $t$  and  $s$ ,  $\tilde{s}$  is obtained by translating  $\hat{t}$  back to  $\mathcal{S}$ , and  $\tilde{t}$  is obtained by translating  $\hat{s}$  back to  $\mathcal{T}$ .  $\tau$  and  $\lambda$  are hyperparameters.

The round-trip loss is inspired by the cycle consistency loss pioneered by Zhu et al. (2017) in the context of GANs. The only application of this concept to the field of machine translation of which we are aware is Su et al. (2018), who adapt it for unsupervised multi-modal machine translation. Here, we apply the idea to supervised machine translation, motivated by the intuition that encouraging the model to generate round-tripable translations may help it learn a semantically meaningful representation. A related idea is that of back-translation, pioneered by Sennrich et al. (2016). Sennrich et al. propose to augment the parallel training corpus used to train a machine translation system with synthetic data, obtained by translating a monolingual corpus in the target language to the source language using an independently trained system. They argue that this is beneficial in particular when parallel training data is scarce. The difference with our approach is two-fold: i) in our approach, the two networks are trained *jointly*, each with their own round-trip loss term, whereas in back-translation, the models are trained separately, with only one of them benefiting from back-translation; ii) we do not assume the existence of a separate monolingual corpus in the target language, but work strictly with a parallel corpus. Having ground truth available, we are thus able to use teacher forcing in constructing the round-trip loss contribution, greatly speeding up training.

Our results show that while incorporating our proposed round-trip loss has little effect on the average BLEU score, the perceived quality of the predicted translations does improve in many cases. We conjecture that the addition of the loss term does, indeed, regularize the model towards semantically meaningful internal representations, but that this effect is not fully captured by the BLEU score.

The remainder of this manuscript is organized as follows. Section 2 describes the model architecture and our implementation of it. Section 3 details the results of our experiments with the proposed round-trip loss. Section 4 provides a discussion and concludes.

## 2 Models and Methods

### 2.1 Model Architecture

For deep neural networks to perform sequence translation, some form of memory is required, as words in a sequence generally depend on words in other parts of the sequence. As an example, completing the phrase “My father is a winegrower, so unsurprisingly he likes to drink ...” is greatly aided by the context provided earlier in the sequence.

Recurrent neural networks achieve this via an autoregressive structure. Their downside is that they are inherently sequential in nature, rendering them difficult to parallelize and hence computationally suboptimal. Convolutional neural networks, on the other hand, are easily parallelizable, but mostly exploit local structure while struggling with long-term dependencies.

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<sup>1</sup>We originally experimented with a seq2seq model, but found training to be too slow.

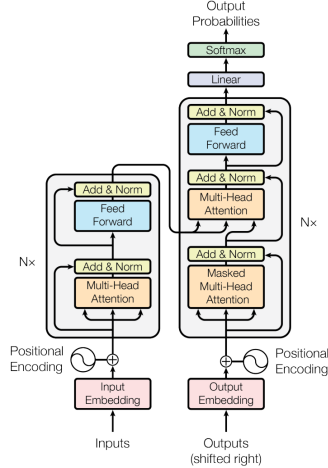


Figure 1: Architecture of the Transformer model. Image credit: Vaswani et al. (2017).

The Transformer model solves this dilemma by exclusively relying on attention — or more precisely, self-attention — to capture global dependencies between input and output, without relying on recurrence or convolutions. The model consists of an encoder and decoder, each of which stacks  $N$  identical layers (the base Transformer in Vaswani et al. (2017) uses  $N = 6$ ). The encoder maps the input sequence to a continuous representation, which is in turn used by the decoder to generate the output sequence.

The first encoder layer takes as input a positional encoding and the embeddings of the input sequence generated by an embedding layer. The positional information allows the Transformer to use the order of the sequence. Each encoder layer then consists of two components: a multi-headed self-attention layer and a feed-forward neural network, with residual connections around them. The self-attention mechanism takes an input vector of length  $d_{\text{model}} = 512$  from the previous layer and projects it to obtain eight key, value, and query vectors of length 64, one each for every attention head. An attention head uses the query and key vectors to generate a softmax over the values and computes its output by multiplying the values and the softmax activations. The outputs of all attention heads are then concatenated to a vector of length  $d_{\text{model}}$  and fed through the feed-forward network, which consists of two linear layers, the inner of which has size  $d_{\text{ff}} = 2048$ . The outputs of the feed forward network are passed to the next encoder layer.

The decoder layers are similar, but add one more sublayer: a masked attention mechanism over the encoder outputs. The final decoder layer is followed by a linear layer and a softmax layer to produce the desired output probabilities. The model architecture is visualized in Figure 1.

## 2.2 Implementation and Training Details

We use the Transformer implementation in TensorFlow 2.0 available from the [tensorflow](https://www.tensorflow.org/) website and implement a custom training loop, which instantiates the  $\mathcal{S} \mapsto \mathcal{T}$  and  $\mathcal{T} \mapsto \mathcal{S}$  models and trains them jointly with the loss described in (1). Our code is available at <https://github.com/s-broda/nmt>.

We train our models on the WMT’14 English – German data set. The training set consists of 4,508,785 sentence pairs, of which we retain those in which source and target sequence both have a length of 40 or fewer tokens to keep the computational demands manageable (the original Transformer model in Vaswani et al. (2017) uses a maximal sequence length of 65). We employ a subword tokenizer and experiment with relatively small target vocabulary sizes ( $2^{13}$  and  $2^{14}$ ), again to keep computational demands at bay (a production system would likely use a vocabulary at least twice as large). Compared to the base Transformer, we also reduce the number of layers from 6 to 4,  $d_{\text{model}}$  from 512 to 128, and  $d_{\text{ff}}$  from 2048 to 512. The number of attention heads is kept at 8. With these choices, training the model (which consists of two Transformers) for a single epoch on the entire dataset takes about 72 minutes on a single NVIDIA GTX1080 Ti. We use the same learning rate schedule as Vaswani et al. (2017), which slowly increases the learning rate to around 0.0014 over 4000 warmup steps, and decays it thereafter.

At test time, we rely on the beam search decoder implementation from [tensor2tensor](https://github.com/tensor2tensor/tensor2tensor). We use a beam width of 10 and a length penalty of  $\alpha = 0.65$ , per the recommendations of Wu et al. (2016). We assess the quality of the translations of the 3,003 sentences in the test set both subjectively and using the BLEU score (Papineni et al., 2002), computed using the `nltk` package. Only the translations from  $\mathcal{S}$  (German) to  $\mathcal{T}$  (English) are scored.

### 3 Results

#### 3.1 Effect on BLEU Score

In order to evaluate the effect of our proposed round-trip loss on the BLEU score, we conduct a number of experiments. First, we train and evaluate the model from scratch for different values of  $\lambda$ . This corresponds to setting  $\tau = 0$  in (1). We observe that validation accuracy stops improving after about 15 epochs, so unless noted otherwise, this is the value we use throughout. The results after training each model for these 15 epochs are shown in Table 1.

$\lambda$	0.0	0.02	0.05	0.1	0.2	0.3	0.4	0.6
$\nu = 2^{13}$	11.69	11.00	10.34	<b>11.89</b>	10.65	9.75	11.29	11.19
$\nu = 2^{14}$	<b>12.38</b>	11.81	12.04	12.11	12.23	12.15	11.80	11.68

Table 1: BLEU scores for models trained from scratch, for different target vocabulary sizes  $\nu$ .

The results are inconclusive. For vocabulary size  $\nu = 2^{13}$ , while the best score is obtained with  $\lambda = 0.1$ , there is very little variation in the resulting scores within the range of  $\lambda$  values tested. With vocabulary size  $\nu = 2^{14}$ , the picture is similar, although the best score is now obtained with  $\lambda = 0$  (i.e., no round trip loss).

In our next set of experiments, we pre-train a model without round-trip loss ( $\lambda = 0$ ), and then fine-tune it for another 15 epochs using the same values for  $\lambda$  as before. This corresponds to a non-zero value of  $\tau$  in (1). As before, we use both  $2^{13}$  and  $2^{14}$  as our vocabulary size, and set  $\tau = 12$  for the former and  $\tau = 15$  for the latter. For comparison, we also trained a model with  $\lambda = 0$  for  $\tau + 15$  epochs. The results are shown in Table 2.

$\lambda$	0.0	0.02	0.05	0.1	0.2	0.3	0.4	0.6
$\nu = 2^{13}$	<b>12.24</b>	12.05	11.72	11.83	11.95	12.07	11.94	11.67
$\nu = 2^{14}$	<b>13.27</b>	11.52	12.62	12.86	12.71	12.59	12.60	12.44

Table 2: BLEU scores for pre-trained models after fine tuning for 15 epochs, for different target vocabulary sizes  $\nu$ .

The results are qualitatively similar to those without pre-training, except that the best score is now obtained with  $\lambda = 0$  for both vocabulary sizes.

In a final set of experiments, we aimed to compare our proposed round-trip loss to the back-translation approach of Sennrich et al. (2016). Note that even when trained without round-trip loss ( $\lambda = 0$ ), our implementation always trains two models jointly, one for translating  $\mathcal{S} \mapsto \mathcal{T}$  and one for  $\mathcal{T} \mapsto \mathcal{S}$ . Thus, after training on a subset of the data for 15 epochs, we used the model to translate part of the remaining training data from  $\mathcal{T} \mapsto \mathcal{S}$ , and then augmented the training data in the source language with these synthetic data. We then trained a model from scratch on this augmented data set and evaluated it as usual. Unfortunately, these experiments were heavily constrained by computational time, mostly because translation is very costly: our implementation will translate roughly 3,000 sentences per hour. As such, we decided to back-translate only around 0.5% (21,600 sentences) of the training data. To allow this small augmentation to make a difference, we restricted the ground truth part of the data to 10% of its original size. We also restrained ourselves to a tokenizer with a target vocabulary size of  $2^{13}$  to further reduce computational cost.<sup>2</sup> With these restrictions, all models (with and without round trip loss) resulted in BLEU scores below 1. These do not allow for a proper comparison and are thus not reported here.

#### 3.2 Qualitative Assessment

We now turn to assessing the translations generated by our models qualitatively. We focus on the model pre-trained without round-trip loss for 15 epochs ( $\tau = 15$ ), and then fine-tuned with  $\lambda = 0.1$ ; this model, called  $\mathcal{M}_{\text{RTL}}$  in the sequel, attains an average BLEU score of 12.86; cf. Table 2. Table 3 presents twelve example translations for which the difference in BLEU score between  $\mathcal{M}_{\text{RTL}}$  and the model without round-trip loss,  $\mathcal{M}_{\text{Vanilla}}$ , is particularly large.

The six sentences in the top half of the table are examples for which the addition of our proposed loss term *improves* the BLEU score substantially. Subjectively, it is apparent that the translations generated by  $\mathcal{M}_{\text{RTL}}$  indeed capture the meaning of the source sentence more adequately. This is perhaps not entirely surprising, given that the

<sup>2</sup>We experimented both with using the original tokenizer trained on the entire dataset, and a tokenizer trained on only the subset used for training.

Source	Target	Prediction, $\lambda = 0$	BLEU	Prediction, $\lambda = 0.1$	BLEU
Das Gebäude, eine Werkstatt mit integrierter Stallung für zwei Pferde, war nicht einfach zu sichern.	The building, a workshop with integrated stabling for two horses, was not easy to secure.	The building, an integrated workshop for two horses was not easy.	0.0	The building, a workshop with integrated pilgrimage for two horses, was not easy to safeguard.	72.8
Auch zu Eiern gibt es pflanzliche Alternativen.	There are also plant alternatives to eggs.	There are also vegetable alternatives.	0.0	There are also vegetable alternatives to eggs.	50.0
Seit 2008 haben er und seine Freiwilligengruppe knapp 32.000 Menschen geholfen.	Since 2008, he and his group of volunteers have helped nearly 32,000 people.	He has been helping almost 32,000 people since 2008 and his voluntary group.	0.0	Since 2008 he and his volunteer group have helped nearly 32,000 people.	46.1
Alle sind weiterhin voll motiviert bei der Sache.	Everyone is still fully motivated for the task at hand.	Everyone continues to be fully motivated by the matter.	0.0	Everyone is still fully motivated on the matter.	38.9
New York City erwägt ebenfalls ein solches.	New York City is looking into one.	New York City also looks like such.	0.0	New York City is also considering such.	36.6
Medien berichteten außerdem von mehreren Verletzten.	The media also reported that several people injured.	Media also reported by several injuries.	0.0	The media also reported several injuries.	34.2
Der öffentliche Nahverkehr werde auch teurer.	Local public transport will also become more expensive.	Public transport will also become more expensive.	74.2	Public transport will also be more expensive.	0.0
In diesem Jahr wurde er Europameister in dieser Spezialdisziplin.	This year he became European Champion in this special discipline.	This year he became European mayor in this special discipline.	70.2	This year, he became Europe's masters in this special discipline.	34.1
Das Wüstenfahrzeug des Vereins wurde auch gezeigt.	The organisation's desert vehicle was also shown.	The organisation desert vehicle was also shown.	67.5	The club's desert vehicle has also been displayed.	0.0
Die genaue Ursache für das Feuer war zunächst nicht klar.	The precise cause of the fire was initially unclear.	The exact cause of the fire was not clear.	42.7	The exact cause of fire was not clear first.	0.0
Eine Sache, auf die ich mich jedes Halloween dann doch wieder freue, sind die Trendwerte.	One thing I do look forward to every Halloween are the trends.	One thing I look forward to every Halloween is the trendy value.	40.9	One thing I am looking forward to each Halloween is the trend values.	0.0
Schauspieler Orlando Bloom hat sich zur Trennung von seiner Frau, Topmodel Miranda Kerr, geäußert.	Actor Orlando Bloom announced his separation from his wife, supermodel Miranda Kerr.	Actor Orlando Bloom has spoken for separation from his wife, Top Model Miranda Kerr.	37.7	Actors Orlando Bloom has spoken to the separation of his wife, Top Model Miranda Kerr.	0.0

Table 3: Example translations. Top half, examples for which the round-trip loss improves the BLEU score; bottom half, examples for which it reduces it.

sentence pairs were selected by maximizing the difference in translation quality (as measured by the BLEU score). What is more revealing is to consider the examples in the bottom half of Table 3. These are examples for which  $\mathcal{M}_{\text{RTL}}$  attains a substantially *lower* BLEU score than  $\mathcal{M}_{\text{Vanilla}}$ . Yet, again judging subjectively, the predictions from  $\mathcal{M}_{\text{RTL}}$  appear equally, or in some cases *more*, accurate than those produced by  $\mathcal{M}_{\text{Vanilla}}$ .

## 4 Discussion and Conclusions

In this work, we proposed to augment a neural machine translation system with a round-trip loss, inspired by the cycle consistency loss of Zhu et al. (2017). Our experiments show that while the additional loss term has little effect on the BLEU score of the translations, it does in many cases result in an improved semantic correspondence between source sequence and translation. As a purely matching-based metric, BLEU cannot capture this. It would be interesting to assess our round-trip loss in terms of alternative metrics that better capture semantic similarity, such as METEOR (Denkowski and Lavie, 2014) or SIMILE (Wieting et al., 2019), but this is beyond the scope of the current manuscript. It is also of interest to explore alternative means of regularizing a neural machine translation system towards round-tripable translations. One potential avenue would be to add a regularization term that penalizes the squared norm of the difference between the outputs of the encoders of the two models  $\mathcal{S} \mapsto \mathcal{T}$  and  $\mathcal{T} \mapsto \mathcal{S}$ . We leave these experiments to subsequent work.

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