Not All Errors Are Equal: Learning Text Generation Metrics using Stratified Error Synthesis

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Abstract

Is it possible to build a general and automatic natural language generation (NLG) evaluation metric? Existing learned metrics either perform unsatisfactorily or are restricted to tasks where large human rating data is already available. We introduce SESCORE, a model-based metric that is highly correlated with human judgements without requiring human annotation, by utilizing a novel, iterative error synthesis and severity scoring pipeline. This pipeline applies a series of plausible errors to raw text and assigns severity labels by simulating human judgements with entailment. We evaluate SESCORE against existing metrics by comparing how their scores correlate with human ratings. SESCORE outperforms all prior unsupervised metrics on multiple diverse NLG tasks including machine translation, image captioning, and WebNLG text generation. For WMT 20/21 En-De and Zh-En, SESCORE improve the average Kendall correlation with human judgement from 0.154 to 0.195. SESCORE even achieves comparable performance to the best supervised metric COMET, despite receiving no human-annotated training data.

1 Introduction

Text generation tasks such as translation and image captioning have seen considerable progress in the past few years (Chen et al., 2015; Birch, 2021). However, precisely and automatically evaluating generated text quality remains a challenge. Long-dominant n-gram-based evaluation techniques, such as BLEU (Papineni et al., 2002) and ROUGE (Lin, 2004), are sensitive to surface-level lexical and syntactic variations, and have been repeatedly reported to not well correlate to human judgements (Zhang* et al., 2020; Xu et al., 2021).

Multiple learned metrics have been proposed to better approximate human judgements. These metrics can be categorized into unsupervised and supervised methods based on whether human ratings are used. The former includes PRISM (Thompson and Post, 2020), BERTScore (Zhang* et al., 2020), BARTScore (Yuan et al., 2021), etc. The latter includes BLEURT (Sellam et al., 2020), COMET (Rei et al., 2020) etc.

Unsupervised learned metrics are particularly useful as task-specific human annotations of generated text can be expensive or impractical to gather at scale. While these metrics are applicable to a variety of NLG tasks (Zhang* et al., 2020; Yuan et al., 2021), they tend to target a narrow set of aspects such as semantic coverage or faithfulness, and have limited applicability to other aspects, such as fluency and style, that matter to humans (Freitag et al., 2021a; Saxon et al., 2021). While supervised metrics can address different attributes by modeling the conditional distribution of real human opinions, training data for quality assessment is often task- and domain-specific with limited generalizability.

We introduce SESCORE, a general technique to produce nuanced reference-based metrics for automatic text generation evaluation without using human-annotated reference-candidate text pairs. Our method is motivated by the observation that a diverse set of distinct error types can co-occur in candidate texts, and that human evaluators do not view all errors as equally problematic (Freitag et al., 2021a). To this end, we develop a stratified error synthesis procedure to construct (reference, candidate, score) triples from raw text. The candidates contain non-overlapping, plausible simulations of NLG model errors, iteratively applied to the input text. At each iteration, a severity scoring module isolates individual simulated errors, and assesses the human-perceived degradation in quality incurred. Our contributions are as follows:

- SESCORE, an approach to train automatic text evaluation metrics without human ratings;
- A procedure to synthesize different types of...
errors in text at varying severity levels;
• Experiments showing that SES CORE is effective in a diverse set of NLG tasks including WMT 20/21, WebNLG, and image captioning, and outperforms all previous unsupervised learned metrics. It is even comparable to the best learned metric on WMT 20/21.

2 Related Work

Traditional n-gram matching based (Papineni et al., 2002; Banerjee and Lavie, 2005) and edit distance based approaches (Levenshtein, 1965; Snover et al., 2006) have proven to be limited in recognizing semantic similarity beyond the lexical level. Learned metrics (Zhang* et al., 2020; Sellam et al., 2020; Yuan et al., 2021) have been proposed to align better with human judgements. We categorize these metrics as either unsupervised or supervised with respect to learning from human-annotated scores.

Unsupervised Metrics attempt to extract features from large pretrained models. Embedding-based metrics (e.g. BERTScore (Zhang* et al., 2020) and Moverscore (Zhao et al., 2019)) create soft-alignments between reference and hypothesis in the embedding space. However, they are refined in the semantic coverage. Text generation-based metrics (Yuan et al., 2021), use conditional probability of the generated sentence to evaluate faithfulness of the candidates. However, Freitag et al. (2021a) points out text generation evaluation can produce errors beyond semantic coverage or faithfulness (e.g. style and fluency errors), which results poor correlations to the human evaluations.

Supervised Metrics attempt to learn through limited human-labelled severity annotations. Rei et al. (2020) trained COMET on a small set of domain-specific human ratings; this model has limited extensibility to the general domain. BLEURT (Sellam et al., 2020) first pretrains on millions of synthetic data and then uses WMT testing data in fine-tuning the model. Unlike our fine-grained stratified error synthesis, the labels on the synthetic data are derived from prior metrics or other tasks, limiting the quality and precision of pretraining process.

3 The SESCORE Approach

Given a reference text \( x \) and a candidate \( y \), a metric is expected to output a score \( s \). Training such a metric model requires triples of reference-candidate-score’s. However, there are no large-scale human annotated triple data available in many tasks. We consider a general setup where large raw text corpus is available.

SESCORE is trained from a pretrained language model (e.g. BERT) on synthetic triples generated from raw text. It synthesizes candidate sentences \( y' \) to mimic plausible errors by transforming raw input sentences \( x \) multiple times. At each step, it inserts, deletes, or substitutes a random span of text. These errors are non-overlapping. It assesses the severity of the errors introduced in the transformation. This allows us to pretrain quality prediction models on corpora containing only raw text samples \( \{x\} \), enabling the use of learned quality prediction models in any text generation domain.

The process of generating \( y' \) from \( x \), stratified error synthesis, is so called for its incremental and multi-category nature; a stochastic perturbation function \( G_{es} \) which randomly samples from a set of potential errors is recursively applied on \( x \) (eq. (1)) \( M \) times to produce a sequence of perturbed sentences \( Z = \{z_i\}_{i=1}^M \) that interpolate between the raw text \( x \) and the final synthetic sentence \( y' = z_M \) (§ 3.2).

\[
z_i = \begin{cases} x, & \text{if } i = 0 \\ G_{es}(z_{i-1}), & 0 < i \leq M \end{cases}
\]

(1)

The stratum sentence sequence \( Z \) is then used to in the subsequent severity scoring step which uses a pairwise severity scoring function \( S_{es} \) on consecutive pairs and cumulatively yield training labels \( s' = \sum_{i=1}^M S_{es}(z_{i-1}, z_i) \) (§ 3.3). A concrete example is illustrated in fig. 2. Finally, we train SESCORE’s quality prediction model, \( f_0 \) (fig. 1) using synthetic \( \{\langle x, y', s'\rangle\} \) triples (§ 3.4).

3.1 Background: Quality Measured by Errors

Our method is inspired by the multidimensional quality metrics (MQM) (Mariana, 2014; Freitag
He will not accept it because he will not like it

Step 1: Insertion: He will not accept it because he hates the plan he will not like it

Step 2: Deletion: He will accept it because he hates the plan he will not like it

Step 3: Replace: He will accept it because he hates the plan he will not fancy it

Step 4: Swap: He will accept it because he hates the plan he will not fancy it

Figure 2: SESCORE: stratified error synthesis and severity scoring Pipeline. × indicates the start index of each error in the previous sentence. Both MLM and Seq-to-seq models can be used to produce inserted or replaced tokens. Each \( z_i \) corresponds to a perturbed sentence. The final synthesized sentence \( y' \) has the score

\[
S' = \sum_{i=1}^{4} S_{es}(z_{i-1}, z_i) = -12.
\]

Table 1: Error Categories in MQM and our synthesis procedure. SESCORE generalizes the imitate model output errors beyond machine translation.

<table>
<thead>
<tr>
<th>Category</th>
<th>MQM Description</th>
<th>Synthesis Procedure in SESCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Addition</td>
<td>Text includes information not present reference.</td>
<td>Insertion using MLM or seq2seq generation</td>
</tr>
<tr>
<td>Omission</td>
<td>Text is missing content from the reference</td>
<td>Delete a random span of tokens</td>
</tr>
<tr>
<td>Mistranslation</td>
<td>Text does not accurately represent the reference</td>
<td>Replace a random span using masked or seq2seq generation</td>
</tr>
<tr>
<td><strong>Fluency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punctuation</td>
<td>Incorrect punctuation (for locale or style)</td>
<td>Insertion &amp; replacement using masked filling, and deletion</td>
</tr>
<tr>
<td>Spelling</td>
<td>Incorrect spelling or capitalization</td>
<td>Insertion, replacement, deletion, and Swap</td>
</tr>
<tr>
<td>Grammar</td>
<td>Problems with grammar</td>
<td>Insertion, replacement, deletion, and Swap</td>
</tr>
</tbody>
</table>

Our technique is stratified so as to enable accurate evaluation of the severity at each step, and prevent subsequent errors from overwriting prior ones. To achieve this, we propose a novel stratified error synthesis algorithm. For an input sentence \( x \), with \( L \) tokens, we initialize an array \( q \) of length \( L \), with \( q_j = L - j, \forall 1 \leq j \leq L \). Values indicate the number of tokens after the current token can be modified with the perturbation function, \( G_{es} \). Each \( G_{es} \) will randomly select a start index \( j \) from 1 to \( L \) to modify the text. We define an error synthesis table to keep track of the number of candidate tokens can be modified after index \( j \). \( G_{es} \) will only be accepted if \( q_j \) is greater than the span length of the perturbation. The implementation details of stratified error synthesis algorithm regarding to each edit operation is illustrated in Appendix A algorithm 1. All perturbations are recursively applied to the raw text \( x \), shown in eq. (1).

3.2 Stratified Error Synthesis

Tuan et al. (2021) suggest that multiple errors could co-occur in one segment, so we construct each sentence with up to \( M_{\text{max}} \) perturbations (≈ 5 in experiments). At each iteration, we randomly draw one perturbation \( G_{es} \) from the set of edit operations, \( E = \{ e_{\text{ins}}, e_{\text{del}}, e_{\text{repl}}, e_{\text{swap}} \} \) (insertion, deletion, replacement, and swap, respectively).
sampling \((k = 4)\), to randomly select the filling token. Our primary aim is to introduce semantically close sentences with all three fluency errors. With the insertion of \(<\text{mask}>\), we can further synthesize Addition errors. For the second approach, we use a pre-trained seq-to-seq model (e.g. mBART) to generate a phrase given the context text, with variable length.

**Synthesize Omission Error by Deletion** \((e_{\text{del}})\)

We delete a random span of tokens from a raw text sentence. The span is drawn uniformly within the token indices. The length of the span is drawn from a Poisson distribution \((\lambda_d = 1.5)\). Our primary aim is to mimic Omission error. However, depending on the specific words that it drops, this technique can further create Mistranslation and all Fluency errors.

**Synthesize Phrasal Error by Replacement** \((e_{\text{repl}})\)

Sometimes specific terms in a reference sentence are systematically misphrased in generated samples. This is difficult to simulate. Instead, we use either an MLM or a seq-to-seq model to replace a segment of tokens in the original text. For the first approach, the replaced span is always a single token, which is first replaced with a \(<\text{mask}>\) token. We then use an MLM to fill the blank similar to the insertion operation. For the second approach, we use a denoising seq-to-seq model (e.g. mBART) to generate tokens for the mask tags. We randomly choose the starting index of the span and draw the span length from a Poisson distribution \((\lambda_d = 1.5)\). We use a denoising seq-to-seq model like mBART to synthesize fluent sentences with Addition and Mistranslation errors.

**Synthesize Grammar and Other Errors by Swapping** \((e_{\text{swap}})\)

We swap two random words within the span length \(\lambda_s\) in the sentence \((\lambda_s = 4)\). Our primary aim is to generate grammatically incorrect sentences with mismanagement of word orders, such as subject verb disagreement. It further introduces Spelling and Punctuation errors.

### 3.3 Assessing Severity Score

Following Freitag et al. (2021a), we consider an error severe if it alters the core meaning of the sentence. Prior study has suggested that sentence entailment is strongly correlated to semantic similarities (Khobragade et al., 2019). To capture the change of semantic meaning, we define a bidirectional entailment relation such that, \(\text{text } a \text{ entails } b\) and \(b\) entails \(a\) is equivalent to \(a\) is semantically equivalent to \(b\). Therefore, for a given perturbation function \(G_{es}\) on the sentence \(z_{i-1}\), we measure a bidirectional entailment likelihood of \(z_{i-1}\) and \(z_i\) if after applying transformation on \(z_{i-1}\), \(z_i\) remains bidirectional entailed to \(z_{i-1}\), we can assume that \(G_{es}\) does not severely alter the semantic meaning of \(z_{i-1}\) and therefore it is a minor error. We define the entailment likelihood, \(\rho(a, b)\), as the probability of predicting \(a\) entails \(b\). The math formulation is illustrated in eq. (2). Setting the threshold \(\gamma\) to be 0.9 reaches the highest inter-rater agreement of severity measures using our validation dataset. Following Freitag et al. (2021a), we assign \(-5\) to severe error and \(-1\) to minor errors. Therefore, our range of score is \([-25, 0]\). We evaluate severity at each perturbation of the sentence and cumulatively yield training label \(s'\) for the final synthesized sentence \(y'\).

\[
S_{es}(z_{i-1}, z_i) = \begin{cases} 
-1, & \text{if } \rho(z_{i-1}, z_i) \geq \gamma \text{ and } \rho(z_i, z_{i-1}) \geq \gamma \\
-5, & \text{otherwise}
\end{cases}
\]

(2)

### 3.4 Quality Prediction Model

In fig. 1, we fed both raw text \(x\) (reference) and synthetic error sentence \(y'\) into a pre-trained language model (e.g. BERT or RoBERTa). The resulting word embeddings are averaged pooled to derive two sentence embeddings. Then we use the approach proposed by RUSE (Shimanaka et al., 2018) to extract the two features: 1) Element-wise synthesized and reference sentence product. 2) Element-wise synthesized and reference sentence difference. Following the COMET (Rei et al., 2020) implementation, the above features are concatenated into a single vector and fed into a feed-forward neural network regressor, \(f_\theta\).

However, the key distinction between our model and COMET is that we don’t use model source input during training or inference. Therefore our SESCORE can generalize to other text generation tasks, without considering specific source data. The detailed architecture choice can be found in § 4.1.

### 4 Experiments

We conduct experiments on three tasks: machine translation, data-to-text and image captioning, to verify the utility and generalizability of SESCORE. Specifically, we compare SESCORE on WMT 2020.
and 2021 test sets in English-to-German (En-De) and Chinese-to-English (Zh-En) with MQM labels (Mariana, 2014; Freitag et al., 2021a), which consists of expert-labeled scores. For data-to-text, we test SEScore on the WebNLG 2017 challenge (Gardent et al., 2017a). For image captioning, we test SEScore on the COCO image captioning challenge 2015 (Chen et al., 2015). We use Freitag et al. (2021a) annotated TED dataset as our development set to select the hyper-parameters in Error Synthesis Models and SEScore Metric Model. We comprehensively analyze each component of our pipeline and their contributions to the final results.

4.1 Pre-training setup

Synthetic Error Data We use the WMT19 (Barrault et al., 2019) training News Complimentary dataset (Tiedemann, 2012) as the raw pretraining data. It contains News articles across 16 different languages. We randomly sampled 40K sentences for English and 10K for German, then generated error synthetic sentences from them. To adopt to the text domain of WebNLG and Image captioning, we generate 30k and 40k error synthetic sentences from the text portion of the WebNLG (Gardent et al., 2017b) and image captioning’s training data (Chen et al., 2015). We use those data to train two separate checkpoints for WebNLG and image captioning evaluations. We discuss the effects of cross-domain evaluation in Appendix D.1.

Error Synthesis Models We use four pretrained language models in the error synthesis process. First, we use an mBART model (Liu et al., 2020) to generate a span of tokens for the \(<\text{mask}>\) positions for both insertion and replacement operations. Second, we use an XLM-RoBERTa model (Conneau et al., 2020) to predict a token for \(<\text{mask}>\) using MLM’s objective for both single token insertion and single token replacement. Finally, we use RoBERTa models fine-tuned on MNLI and XNLI as our entailment classification model for English and German respectively. These two models are used to determine the bidirectional relations of a synthetic sentence and a raw text to measure the severity of the synthetic text. We set the synthesis hyperparameters \(\lambda_e = 5\), \(\lambda_d = 1.5\), \(\lambda_r = 1.5\), and \(\lambda_s = 4\). We generate all synthesized dataset on one RTX A6000 GPUs. It costs 0.5 hours to generate 10K sentences.

SEScore Metric Model. To ensure the fair comparison and fully demonstrate the power of our pretraining data, SEScore uses the comparable model size compared to the COMET (Rei et al., 2020). Specifically, we use XLM-RoBERTa Large as the backbone for our German metric model and RoBERTa Large for English metric model. We use Adam optimizer (Kingma and Ba, 2017) and set batch size, learning rate and dropout rate of 8, 3e-5 and 0.15 respectively. We use mean squared error to train the metric model. We select the best checkpoint based on the highest Kendall correlation on the TED validation. We include detailed training process and hyperparameters in the Appendix B.1.

4.2 Baseline Methods

For machine translation evaluation, we include three WMT baseline methods and five best performed learned metrics. They are (1) Ngram- and distance-based metrics (BLEU (Papineni et al., 2002), ChrF (Popović, 2015) and TER (Snover et al., 2006)); (2) learned metrics requiring human rating data (COMET (Rei et al., 2020), BLEURT (Sellam et al., 2020)); (3) learned metrics without human rating data (PRISM (Thompson and Post, 2020), BARTScore (Yuan et al., 2021) and BERTScore (Zhang et al., 2020)). For WebNLG evaluation, we include the three baselines in prior work (Gardent et al., 2017b): METEOR (Banerjee and Lavie, 2005), TER, BLEU, and two learned metrics MoverScore (Zhao et al., 2019) and BERTScore. For image captioning, we include five baseline models in the COCO image captioning challenge 2015 (Chen et al., 2015): BLEU, METEOR, ROGUE-L (Lin, 2004), CIDEr (Vedantam et al., 2015) and ChrF. We further include BARTScore and BERTScore and one top-performing task-specific learned metric, LEIC (Cui et al., 2018). For all the learned metrics with variants, we choose their checkpoints based on their paper recommendations. We discuss the details of the baseline model setups in the Appendix C.1.

4.3 Evaluation Procedure

Machine Translation Task As WMT20’s standard practice (Mathur et al., 2020), we compute the correlations of each evaluation metric to the segment- and system- level human scores, on WMT20 and WMT21, with MQM-based labels (Freitag et al., 2021a). For the segment-level correlation, we adopt the Kendall \(\tau\) correlation from WMT20 to evaluate the relative rankings between segments of the different systems. For the correlation of system-level scores, we average SEScore
Table 2: Segment-level Kendall ($\tau$) and System-level Pearson correlation ($|\rho|$) on En-De and Zh-En for WMT2020 and WMT 2021 Testing sets with Expert-based MQM labels. * indicates that SES CORE significantly outperforms baselines with p values < 0.05.

for all reference-candidate pairs of each machine translation system and estimate the absolute Pearson correlation $|\rho|$ to the system-level human judgement scores.

Data-to-Text Task Following the WebNLG challenge (Gardent et al., 2017b), we use Kendall correlation to evaluate the segment-level correlation. Each generated output is annotated by three aspects: semantics, grammar and fluency. Since our SES CORE is the overall score of accuracy and fluency, we average three aspects of human ratings into one overall score and evaluate segment-level Kendall correlation of the SES CORE to the overall human judgement score.

Image Captioning Task Following Zhang* et al. (2020), we compute SES CORE for all reference-candidate pairs of each image captioning system and average all the scores for each system to generate the system-level scores. We compute the system-level Pearson correlation with M3 system-level human judgement score in COCO image captioning challenge (Chen et al., 2015). M3 human judgement measures the average correctness of the captions on a scale 1-5. The detailed task, data information and evaluation procedures are included in the Appendix C.2.

4.4 Results on Machine Translation

In table 2, we show our evaluation results on En-De and Zh-En in both WMT20 and WMT21.

English to German We first contrast SES CORE with three WMT baselines (BLEU, TER and ChrF). SES CORE outperforms them significantly in both system-level Pearson and segment-level Kendall correlations. SES CORE shows its superior performance over two recent unsupervised learned metrics (Bertscore and PRISM) leading by an average 8% and 7% segment-level Kendall correlation in two years’ testing sets. Compared to the supervised models, SES CORE has around 4.4% improvement in the Kendall correlations at WMT20 and 8.8% at WMT21 against BLEURT. Most importantly, SES CORE outperforms the SOTA supervised metric, COMET, by 3.6% in Kendall for WMT21 and 7.3% in system-level Pearson correlation.

Chinese to English Similar to En-De, SES CORE outperforms three WMT baseline models (BLEU, TER and ChrF) by the great margin in both system-level and segment-level correlations of two years’ testing sets. Compared to three strong unsupervised learned metrics, BERTScore, BARTScore and PRISM, SES CORE can outperform them by 4.6% on average in Kendall correlation in WMT20 and average 2.3% in WMT21. Compared to the supervised models, we have 4.3% improvement in the Kendall correlations at WMT20 and 3% at WMT21 against BLEURT. This is significant as BLEURT is previously trained as an English-oriented metric with millions of synthetic data and 5 year’s human rating data (WMT15-19). Moreover, SES CORE outperforms the SOTA supervised COMET model for both segment-level and system-level correlation in WMT20. The remaining gaps of Kendall correlations to the COMET is within 1%.

Takeaways: Machine translation results in En-De and Zh-En demonstrate SES CORE’s superior performance to unsupervised metrics and competitive performance against supervised SOTA metrics.
4.5 Results on WebNLG Challenge

Table 3 shows our segment-level Kendall correlation results for WebNLG Challenge. SESCORE can outperform three baseline models (Meteor, TER and BLEU) significantly. When comparing to the learned metrics, SESCORE outperforms BARTScore and MoverScore significantly by leading 8.2% and 3% improvements on Kendall correlations. Moreover, it improves the top-performing unsupervised metric, BERTScore, by 0.3%.

4.6 Results on Image Captioning Challenge

Table 4 demonstrates our system-level Pearson correlation results for the COCO image captioning challenge. SESCORE outperforms all task-agnostic and task-specific baseline metrics. The correctness metric in image captioning creates a challenge evaluation scenario, such that evaluating only on semantic coverage does not cover all model mistakes. Metrics including METEOR, BLEU, even BERTScore with pretrained word embeddings only yield weak or moderate correlations to the human judgements. SESCORE further outperforms significantly to BERTScore with idf weights and BARTScore which covers faithfulness. Most importantly, SESCORE outperforms two task-specific metrics, LEIC (Cui et al., 2018) and CIDER (Vedantam et al., 2015), by 6.1% and 1.8% Pearson correlations. This is a significant result, as LEIC is a trained metric that takes image as additional inputs, optimized on the COCO data distributions and CIDER is a consensus based evaluation purely used for image descriptions.

Takeaways: Results in § 4.5 and § 4.6 verify our prior assumptions that despite our synthesized error types are originated for Machine Translation tasks, they are useful and applicable to multiple domains and tasks. As benefited from the reference-only evaluation setup, our pretrained evaluation metric can correlate well to the human judgements in various text generation settings, e.g with or without requiring source data to be text.

5 Quantitative Analysis

To validate the proposed SESCORE training technique, we analyze the effects of data quantity, the stratified components, and synthetic error types. We include the cross-domain evaluation in the Appendix D.1. We include a detailed qualitative analysis of SESCORE regarding to its robustness and limitations in Appendix E.

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Kendall</th>
<th>M3 Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>METEOR</td>
<td>-0.388*</td>
<td>0.333</td>
</tr>
<tr>
<td>TER</td>
<td>-0.345*</td>
<td>0.296</td>
</tr>
<tr>
<td>BLEU</td>
<td>0.289*</td>
<td>0.564</td>
</tr>
<tr>
<td>BARTScore</td>
<td>0.317*</td>
<td>0.590</td>
</tr>
<tr>
<td>MoverScore</td>
<td>0.369*</td>
<td>0.688</td>
</tr>
<tr>
<td>BERTScore</td>
<td>0.396</td>
<td>0.720</td>
</tr>
<tr>
<td>SESCORE</td>
<td>0.399</td>
<td>0.781</td>
</tr>
</tbody>
</table>

Table 3: Segment-level Kendall Correlation ($\tau$) on WebNLG 2017. * indicates that SESCORE significantly outperforms baselines with p value < 0.05.

5.1 Data Quantity Effects

We use 10k, 20k, 40k and 120k synthetic error samples to train SESCORE models and evaluate their Kendall correlations on WMT20. We observe that the Kendall correlation reaches an optimal level at 40k synthetic sentences in Zh-En and 10k synthetic sentences in En-De. This demonstrates the potential gap between synthetic and real error distributions. It also indicates that the optimal performance can be achieved through error perturbations with small amount of raw text (see Appendix fig. 4).

5.2 Effects of the Stratified Components

To study the effects of each component, we include the SESCORE w/o synthesized error 2 and SESCORE with without severity measures 3. In table 5, we demonstrate that SESCORE without severity measures can still achieve the strong performance improvements over the base language model, leading average 11% and 5% in segment-level Kendall correlation at En-De and Zh-En, respectively. This result demonstrates that our incremental injection of synthetic errors can achieve high human correlations on the segment-level rankings, providing the first layer of our stratified process. However, without severity measures,

2We mean-pooled the word embeddings from pretrained models (Conneau et al., 2020; Liu et al., 2019) to generate each sentence embedding and compute the cosine similarities of the sentence embeddings for evaluation.
3We remove the severity scoring component in SESCORE by assigning all errors to be minor, with score -1. The final score will be within 0 to -5. We use this new score labeling to pretrain a SESCORE without severity measures.
Table 5: Abalation study on the stratified error synthesis on En-De and Zh-En for WMT2020 and WMT2021. Testing sets with Expert-based MQM labels. * indicates the Pearson correlation has p values < 0.05.

<table>
<thead>
<tr>
<th>Stratified Components</th>
<th>WMT20 (En→De)</th>
<th>WMT21 (En→De)</th>
<th>WMT20 (Zh→En)</th>
<th>WMT21 (Zh→En)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kendall</td>
<td>Pearson</td>
<td>Kendall</td>
<td>Pearson</td>
</tr>
<tr>
<td>SEScore w/o synthesized error</td>
<td>0.129</td>
<td>0.204</td>
<td>0.004</td>
<td>0.457</td>
</tr>
<tr>
<td>SEScore w/o severity measures</td>
<td>0.249</td>
<td>0.549</td>
<td>0.103</td>
<td>0.608*</td>
</tr>
<tr>
<td>SEScore</td>
<td><strong>0.273</strong></td>
<td><strong>0.706</strong>*</td>
<td><strong>0.139</strong></td>
<td><strong>0.629</strong>*</td>
</tr>
</tbody>
</table>

Performance (Kendal Corr.)

Figure 3: Effects of the error types: demonstrating the results achieved when Replace, Insert, Swap, or Delete is separately applied. Dashed line (All $g_{es}$) represents the aggregate performance when all four synthesis functions are used together. The dotted line (0 $g_{es}$) represents the baseline performance of SEScore when none of the error synthesis functions are applied.

SESCORE can hardly determine system level ranking, indicating by weak system-level correlations in Zh-En. By adding the severity measures into our stratified pipeline, we observe a large system-level correlation improvements in both En-De and Zh-En. The segment-level Kendall correlation can be further improved by average 3% in En-De and 2% in Zh-En. This study demonstrates the effectiveness and importance of our stratified components in both segment-level and system-level correlations to human judgements.

5.3 Effects of the Error Types

To understand each error type’s contribution to the final pretraining outcomes, we use each error synthesis function to generate separate synthesized data and use each data to train a SEscore. We benchmark SEscore’s performance with each error synthesis function in both years’ language directions. fig. 3 demonstrates that individual error synthesis function contributes to the pretrained metric differently in different language directions.

In fig. 3, from both En-De and Zh-En, we observe that all four error synthesis functions are effective as they bring up the base Kendall performance of at least 5% from En-De and at least 7% from Zh-En in both year’s testing sets. We observe that the Replace and Delete tasks are the two prominent error synthesis functions in both En-De and Zh-En. On the contrary, the insert operation has the relatively minor effects in both En-De and Zh-En. Our best assumption is that large pretrained language model tends to produce semantically close content when giving the full context of the sentence. Therefore, most of insert produced errors are relatively minor and are not able to simulate Addition error types under diverse severity levels. Lastly, we observe that the swap operation has different effects in different language directions. From Zh-En, the SEscore trained solely on Swap errors can achieve equal to or less than 1% Kendall correlations compared to the SEscore with four different operations. However, in En-De, the swap function only has moderate effects.

Takeaways: We demonstrate that all error synthetic functions can improve Kendall correlations to the human judgements. However, the effect of each error synthetic functions is related to the actual error distributions in each task. Aggregating all four error synthetic functions should be considered to achieve a general error distributions which is robust to different domains or tasks.

6 Conclusion

To conclude, we introduced SEscore, a reference-based metric for text generation evaluations. Without human labels, SEscore can outperform all unsupervised evaluation metrics and achieve com-
petitive performance to the SOTA supervised approaches. We demonstrate that our stratified error synthesis approach makes model aware of individual errors with different severity levels, achieving high correlation to the human judgements.

7 Acknowledgements

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8 Ethics and Limitations

Our qualitative analysis in Appendix E highlights three main limitations in the SESCORE framework. First, we observe that it is difficult for SESCORE to detect punctuation errors. As they are not represented in the entailment data distributions. Second, SESCORE disagrees with human judgements when human annotations contain uncertainties (e.g., high inter-rater disagreement on the severity of an error). Perhaps in these cases human opinions are too inherently subjective to model well in the first place. Regardless, SESCORE is not likely to produce rankings exactly matching human annotators when human rating difference is less than 1. Lastly, SESCORE disagrees more heavily with human annotators on the quality of long generated text passages. We assumed that this is due to our limited sentence embedding space while individual errors will be mitigated by the long sentence contexts. Most importantly, we observed that those three limitations are also commonly occurred in the three top-performing baseline metrics (BERTScore (Zhang et al., 2020), PRISM (Thompson and Post, 2020) and COMET (Rei et al., 2020)), motivating more future works to investigate on those issues. We demonstrate SESCORE’s superior performance over other baselines. However, SESCORE can not be used to replace human judgements. We will support two frameworks of SE5core: SE5core with and without severity measures. SE5core with severity measures can support up to 100 languages that XLM-Roberta pretrained on. SE5core with severity measures currently supports 15 languages: English, French, Spanish, German, Greek, Bulgarian, Russian, Turkish, Arabic, Vietnamese, Thai, Chinese, Hindi, Swahili and Urdu. All code and synthesized data samples will be publicly released following deanonamization.

References


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A Algorithm Details

Algorithm 1: Stratified Error Synthesis

Input: Seed sentence set $S = \{x_1, x_2, ..., x_n\}$, $\lambda_e$, $\lambda_d$, $\lambda_r$, $\lambda_s$, editing model set $M$.
Output: Synthetic reference and error text $D$. 

1. $D = \emptyset$;
2. for $i = 1..n$ do
   3. $l = \text{len}(x_i)$, $y_{new} = x_i$, $s_i = 0$;
   4. $k \sim \text{Poisson}(\lambda_e)$;
   5. for $j = 1..k$ do
      6. $y_{old} = y_{new}$;
      7. $\text{edit} \sim \text{Random}([\text{Ins}, \text{Del}, \text{Rep}, \text{Swap}])$;
      8. switch $\text{edit}$ do
         9. case $\text{Ins}$ do
            10. $h \sim \text{Uniform}(0, l)$ s.t. $h$ does not overlap the previous edited spans;
            11. Randomly select a model from $M$ to generate a phrase $f$ to insert at position $h$ of $y_{new}$;
         12. case $\text{Del}$ do
            13. repeat
            14. $d \sim \text{Uniform}(0, l)$;
            15. $ll \sim \text{Poisson}(\lambda_d)$;
            16. until the span from $h$ to $b + ll - 1$ does not overlap the previous edited spans;
            17. Remove a span of length $ll$ at position $h$ from $y_{new}$;
         18. case $\text{Rep}$ do
            19. repeat
            20. $d \sim \text{Uniform}(0, l)$;
            21. $ll \sim \text{Uniform}(1..\lambda_r)$;
            22. until the span from $h$ to $b + ll - 1$ does not overlap the previous edited spans;
            23. Randomly select a model from the model base $M$ to generate a phrase $f$;
            24. Replace the segment of $y_{new}$ from $h$ to $h + ll - 1$ with $f$;
         25. case $\text{Swap}$ do
            26. repeat
            27. $d \sim \text{Uniform}(0, l)$;
            28. $ll \sim \text{Uniform}(1..\lambda_s)$;
            29. until the span from $h$ to $b + ll - 1$ does not overlap the previous edited spans;
            30. Swap the tokens in $y_{new}$ at positions $h$ and $h + ll$;
      31. $s_i + = S_{ws}(y_{old}, y_{new})$;
      32. $D \leftarrow D \cup \{(x_i, y_{new}, s_i)\}$;

B Implementation Details of the Pretraining Pipeline

This section provides the implementation details for both error synthesis models and SEScore metric model.
B.1 SEScore Metric Model

The feed-forward hidden dimensions are 2048 and 1024. We use tanh as our activation function. The training process takes 1, 3, 2 and 1 epochs for machine translation Zh-En, machine translation En-De, WebNLG and image captioning, respectively.

C Experiments-Supplementary Material

C.1 Details about the Baseline Models

For all model variants, we choose each model based on two criteria: their paper recommendations and comparable model size to SEScore.

For BERTScore (Zhang* et al., 2020), we follow its model recommendation by using roberta-large for English texts and bert-base-multilingual-cased for German texts. For all BERTScore in the paper, we report their F1 scores. For BLEURT (Sellam et al., 2020), we use BLEURT-Large (Max token 128, 24 layers and 1024 hidden units, comparable size to SEScore) for English texts and BLEURT-20-D12 for German texts. For COMET (Rei et al., 2020), we choose their best checkpoint wmt20-comet-da (exactly the same model size to SEScore) to evaluate its performance. We use bart-large-cnn to evaluate BARTScore (Yuan et al., 2021)’s performance. We NLTK (Bird et al., 2009) library to implement BLEU (Papineni et al., 2002), METEOR (Banerjee and Lavie, 2005), CHrF (Popović, 2015) and ROUGE-L (Lin, 2004). We report LEIC (Cui et al., 2018) and CIDEr (Vedantam et al., 2015)’s performance through prior study (Cui et al., 2018).

C.2 Details about the Evaluation Procedures and Test Data Information

Machine Translation Task

We use WMT20 and WMT21 (Freitag et al., 2021b) ’s testing sets (Newtest2020 and Newtest2021), with mqm-based expert labels, as our main evaluation corpus. WMT20 (Chinese→English) contains 2000 segments across 155 documents and WMT (English→German) contains 1418 segments across 130 documents, respectively. WMT21 (Chinese→English) contains 1948 segments and WMT21 (English→German) contains 1002 segments, respectively. There are two types of human judgement scores: Segment-level and System-level scores. Segment-level human judgement score assigns a single score to each reference-candidate pair. System-level human judgement score assigns a single score to each system based on all {reference, system output} pairs. We follow the WMT20’s standard practice to evaluate metric performance using both system-level and segment-level correlation.

For system-level evaluation, we average SEScore for all reference-candidate pairs of each machine translation system and estimate the absolute Pearson correlation $|\rho|$ to the System-level human judgement scores. Freitag et al. (2021b) annotated top 10, 10, 17 and 15 top performing systems of En-De and Zh-En in Newtest2020 and En-De and Zh-En in Newtest2021, respectively.

For segment-level evaluation, we adopt the Kendall $\tau$ correlation from WMT20 (Mathur et al., 2020) to evaluate the relative rankings between segments of the different systems (See Eqn 3). Following the prior study’s suggestion (Freitag et al., 2021a), we use the absolute threshold between two segment scores to determine the relative rankings of both En-De and Zh-En. To prepare all the relative ranking pairs for Kendall correlation, we removed all the pairs which have the exactly same annotations and cleaned erroneous texts. In the end, we have 76,087 pairs from Zh-En and 54405 pairs from En-De in Newtest2020 and 38758 pairs from En-De and 52498 pairs from Zh-En in Newtest2021.

The Kendall’s Tau-like formulation is defined as following:

$$\tau = \frac{\text{Concordant} - \text{Discordant}}{\text{Concordant} + \text{Discordant}}$$

where Concordant indicates the number of the correct predictions in the pairwise ranking and Discordant indicates the number of the misrankings.

Data-to-Text Task

The WebNLG dataset (Gardent et al., 2017b) consists a set of data extracted from DBpedia and requires systems to map entities (e.g., buildings, cities, artists) to text. We use 9 submissions for WebNLG challenge. Each system generates 223 outputs. In total, we have 4,677 output sentences. Following the WebNLG challenge (Gardent et al., 2017b), we use Kendall $\tau$ correlation to evaluate the relative rankings between segments of the different systems. From combinations of rankings and data cleaning, we obtain 7725 relative ranking pairs. Each generated output is evaluated by three aspects: semantics, grammar and fluency. Since our SEScore is the overall score of accuracy and fluency, we average three aspects of human ratings into one overall score and evaluate segment-level Kendall correlation of the SEScore to the overall human judgement score. The Kendall...
τ’s formulation is shown in Eqn 3.

### Image Captioning Task

COCO 2015 Captioning Challenge (Chen et al., 2015) consists of the human judgements from the 11 submission entries. Following the prior study (Cui et al., 2018; Zhang et al., 2020), we perform our experiments on the COCO validation set, as we do not have access to COCO test set where human judgements were performed. Using the findings of the prior works (Cui et al., 2018; Zhang et al., 2020), we argue that the human judgements on the validation set are sufficiently close to the ones on the testing set.

### D Quantitative Analysis

#### D.1 Effects of the Cross Domain Evaluation

As domain shifts have been repeatedly reported by the previous studies (Sellam et al., 2020; Yuan et al., 2021), we conduct experiments to study SEScore before and after domain adaptation in WebNLG and image captioning. In Table 6, due to the close data distribution and error types in WebNLG and machine translation, we find that SEScore pretrained on machine translation error synthetic data can achieve strong cross-domain performance in WebNLG and competitive to in-domain pretrained variant. However, when larger domain difference presents between machine translation and image captioning, domain adaptation plays a major role by leading metric from no correlation of cross-domain performance to high correlation to human judgements. This finding suggests that our domain adaptation strategy is effective in adapting synthetic error sentences into different domains cross several NLG tasks. This technique can provide major benefits in training a powerful learned metrics in narrowed domain, e.g low resource language of machine translation.

<table>
<thead>
<tr>
<th>Task</th>
<th>WebNLG (τ)</th>
<th>COCO (ρ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-domain Performance</td>
<td>0.396</td>
<td>-0.0428</td>
</tr>
<tr>
<td>In-domain Pretraining</td>
<td>0.399</td>
<td>0.781</td>
</tr>
</tbody>
</table>

Table 6: Abalation study on the cross-domain evaluation at WebNLG and COCO image captioning Challenge.

Figure 4: Relationship between data quantity and performance (τ) for Zh-En and En-De translation.

#### D.2 Effects of the Data Quantity

### E Qualitative Analysis

#### E.1 Robustness Analysis

Table 7 shows examples where SEScore disagree largely to the baseline models (BERTScore and PRISM) about the pairwise rankings. We observe that SEScore is effective on distinguishing pairs, which are differed on only one minor error, demonstrated at case No.1 in Table 7, BERTScore suffers greatly when word order is shuffled and fails to capture the shifts in semantic meanings. Minor mistake, like inappropriate use of “subscribers” is hard to reflect to in its overall score. We observe the similar shortcomings in PRISM and COMET. We investigate the robustness of the word order for all automatic evaluation metrics should be similar to the rankings assigned by the human score.
"shares a lot word coverage to the reference, it completely alters the sentence meaning. According to the MQM-based human evaluation criteria (Freitag et al., 2021a), this is a severe error and should be labeled as -5. However, due to their evaluation criteria, both PRISM and BERTScore are incapable in distinguishing such differences. In this analysis, we demonstrate qualitatively that SEScore’s superior performance over unsupervised top-performing metrics (BERTScore and PRISM) and comparative performance to the SOTA supervised metric COMET. Moreover, SEScore demonstrates its better score alignments to the human judgements against other metrics. Its scores are directly interpretable under MQM expert-based human evaluation framework (Freitag et al., 2021a).

E.2 Limitations

Table 8 shows examples where SEScore disagrees with human judgements about the pairwise rankings. We observe that SEScore find it difficult to detect punctuation errors. For example, SEScore fails to correctly rank No.1 where "Worse" example’s punctuation has higher severity error. Second, SEScore disagrees with human judgements when human labels contains uncertainties (Human annotators do not have the agreements on the severity measures), indicating by No.2 and No.3. With the close severity differences (<1 human rating difference), SEScore is not likely to produce rankings exactly matching human annotators. Lastly, for the long text generation with more than 100 words (No.4), we observe that SEScore fails to produce correct rankings or align to the human judgements. We assumed that this is due to our limited sentence embedding space while individual errors will be mitigated by its long sentence contexts. Moreover, we observed that those three limitations are also commonly occurred in the three top-performing baseline metrics (BERTScore, PRISM and COMET), motivating more future works to investigate on those issues.
<table>
<thead>
<tr>
<th>No.</th>
<th>Reference</th>
<th>Model Outputs</th>
<th>Category</th>
<th>Score</th>
<th>BERT-SEScore</th>
<th>PRISM</th>
<th>COMET (Ours)</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>However, Boston Dynamics pointed out that Spot has now entered the stage of mass production and most of its subscribers are construction and energy operators.</td>
<td>However, Boston Dynamics pointed out that Spot has now entered the stage of mass production, and most of its subscribers are construction and energy operators.</td>
<td>Better</td>
<td>0.960</td>
<td>-1.410</td>
<td>0.282</td>
<td>-4.435</td>
<td>-4.333</td>
</tr>
<tr>
<td>2</td>
<td>The person mentioned above said.</td>
<td>The above-mentioned person said.</td>
<td>Better</td>
<td>0.901</td>
<td>-2.345</td>
<td>0.308</td>
<td>-2.112</td>
<td>-2.000</td>
</tr>
<tr>
<td>3</td>
<td>In addition to visa-free and visa-on-arrival arrangements, it is becoming more convenient for Chinese citizens to apply for visas, and the procedures are becoming more and more simplified.</td>
<td>In addition to visa-free and visa-on-arrival arrangements, it is becoming more convenient for Chinese citizens to apply for visas, and the procedures are becoming more and more simplified.</td>
<td>Better</td>
<td>0.939</td>
<td>-1.213</td>
<td>0.808</td>
<td>-1.827</td>
<td>-1.733</td>
</tr>
<tr>
<td>4</td>
<td>The mobile phone client highlights the artificial intelligence voice function, adapts to the trend of mobile communication, and provides users with the portable &quot;China Story&quot; player.</td>
<td>The mobile app features AI speech recognition in accordance with the trend of mobile communication and provides users with a portable &quot;China Story&quot; player.</td>
<td>Better</td>
<td>0.921</td>
<td>-2.590</td>
<td>0.910</td>
<td>-0.046</td>
<td>-1.700</td>
</tr>
</tbody>
</table>

Table 7: Example sentences in 4 relative ranking pairs assigned by BERTScore(F1), PRISM, COMET, SEScore and Human. We use "Better" and "Worse" to indicate the model outputs with higher and lower human ratings, respectively. We include all metric outputs and human labels on the right side of the table. Our SEScore shows its strong correlation to the human judgements while unsupervised baseline models disagree with human ratings significantly. We bold the metric results which produce the correct pairwise rankings. We also underline the error spans in each model output.
### Table 8: Example sentences in 4 relative ranking pairs assigned by BERTScore (F1), PRISM, COMET, SEScore and Human. We use “Better” and “Worse” to indicate the model outputs with higher and lower human ratings, respectively. We include all metric outputs and human labels on the right side of the Table. This table demonstrates some examples where SEScore and human judgement disagree about the ranking. We bold the metric results which produce the correct pairwise rankings. We also underline the error spans in each model output.

| No. | Reference | Model Outputs | Category | Human | Better | 0.940 -2.166 0.706 -1.900 -11.00 | Worse | 0.937 -2.200 0.660 -1.837 -20.00 |
|-----|-----------|----------------|----------|--------|---------|----------------|--------|----------------|---------|
| 1   | The Asian Future section includes three Chinese films. There are 3 Chinese-language films in the “Asian Future” unit. | 0.925 -1.797 0.656 -1.222 -1.667 | Better | 0.950 -1.961 0.586 -3.051 -5.033 |
| 2   | In order to prevent the risk of farmers losing their land, methods such as preferred stock, first lease and then share, and repurchase have been produced. | 0.955 -1.962 0.595 -1.430 -1.430 | Better | 0.990 -2.000 1.000 -0.500 0.500 |
| 3   | To celebrate the 70th Anniversary of the People’s Republic of China and the 20th Anniversary of the Establishment of the Macao Special Administrative Region, the Urban Services Department will conduct a special food safety public guided tour at the Food Information Station on the first floor of the Youhan Hawker Building from October to December at 3:30 pm on Wednesdays. | 0.937 -1.966 0.703 -1.937 -1.937 | Better | 0.999 -2.000 1.000 -0.500 0.500 |
| 4   | Self-driving development in China will become more competitive. | 0.937 -2.370 0.300 -1.635 -1.000 | Better | 0.999 -2.000 1.000 -0.500 0.500 |

**Notes:**
- Bold text indicates the metric results which produce the correct pairwise rankings.
- Underlined text highlights the error spans in each model output.