Contextualized Topic Coherence Metrics

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Abstract

This article proposes a new family of LLM-based topic coherence metrics called Contextualized Topic Coherence (CTC) and inspired by standard human topic evaluation methods. CTC metrics simulate human-centered coherence evaluation while maintaining the efficiency of other automated methods. We compare the performance of our CTC metrics and five other baseline metrics on seven topic models and show that CTC metrics better reflect human judgment, particularly for topics extracted from short text collections by avoiding highly scored topics that are meaningless to humans.

https://github.com/hamedR96/CTC

1 Introduction

Topic models are a family of text-mining algorithms that identify themes in a large corpus of text data (Blei, 2012). These models (Churchill and Singh, 2022) are widely used for exploratory data analysis with the aim of organizing, understanding, and summarizing large amounts of text data (Abdelrazek et al., 2022). Numerous techniques, algorithms, and tools have been employed to develop a variety of topic models for different tasks and purposes (Srivastava and Sutton, 2017) including much recent work on neural topic models (Grootendorst, 2022). However, due to their nature as unsupervised models, comparing topic outputs, hyperparameter settings, and overall model quality has traditionally been difficult (Hoyle et al., 2022).

Topic Coherence (TC) metrics measure the interpretability of topics generated by topic models. These metrics are categorized into two classes: automated TC metrics and human-annotated TC metrics (Hoyle et al., 2021). Automated TC metrics estimate the interpretability of topic models with respect to various factors such as co-occurrence or semantic similarity of topic words. On the other hand, human-annotated TC metrics are protocols for designing surveys that rate or score the interpretability of topic models. Human judgment is often used to validate topic coherence metrics to provide an accurate assessment of the semantic coherence and meaningfulness of a given set of topics (Newman et al., 2009; Aletras and Stevenson, 2013; Mimno et al., 2011). While human-annotated TC metrics incorporate subjective human judgments and provide a more accurate and nuanced understanding of how well topic models are performing (e.g. in terms of their ability to capture the underlying themes in a text corpus), they are expensive, time-consuming, and require multiple human-subjects to avoid personal biases. On the other hand, automated metrics are more cost-effective than human-annotated methods, as they do not require the hiring and training of human annotators, which results in their ability to evaluate large amounts of data and iterate through many model comparisons.

Automated metrics are intended to align more closely with human judgment, providing a better measure of the interpretability of topic words. The risk of such approximations, however, is that they themselves become the target of optimization rather than the underlying property they were intended to measure. Several recent works sug-

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gest that this has occurred especially in the context of neural topic models. Doogan and Buntine (2021) argue that interpretability is ambiguous and conclude that current automated topic coherence metrics are unreliable for evaluating topic models in short-text data collections and may be incompatible with newer neural topic models. In a similar study, Hoyle et al. (2021) show that topics generated by neural models are often qualitatively distinct from traditional topic models while they receive higher scores from current automated topic coherence metrics. Hoyle et al. (2021) conclude that the validity of the results produced by fully automated evaluations, as currently practiced, is questionable, and they only help when human evaluations cannot be performed. Hoyle et al. (2022) in another recent work shows that neural topic models fail to improve on the traditional topic models such as Gibbs LDA (Griffiths and Steyvers, 2004; McCallum, 2002) and consider neural topic broken as they do not function well for their intended use.

To address these problems, we introduce Contextualized Topic Coherence (CTC) metrics which are a context-aware family of topic coherence metrics based on the pre-trained Large Language Models (LLM). Taking Advantage of LLMs elevates the understanding of language at a very sophisticated level incorporating its linguistic nuances, contexts, and relationships. CTC is much less susceptible to being fooled by meaningless topics that often receive high scores with traditional topic coherence metrics.

2 Automated Topic Coherence Metrics

Topic coherence (TC) metrics measure the consistency of topic word representations (topic labels) to evaluate the interpretability and meaningfulness of a topic. Most coherence measure are based on the analysis of topic word co-occurrence distributions within the model input documents. A high TC value indicates that the words in the topic labels are related and describe some semantic notion within a specific context or domain.

Newman et al. (2009, 2010b) claim that Pointwise Mutual Information (PMI) based metrics achieve ratings which are highly correlated with human-annoted ratings. They define UCI which measures the strength of the association between pairs of words based on their co-occurrence in a sliding window of length-l words. Mimno et al. (2011) proposes UMass, an asymmetric confirmation measure that estimates the coherence degree of topic labels by calculating the $\log$ ratio frequency of label word co-occurrences in the corpus of documents. UMass counts the number of times a pair of words co-occur in a given corpus and compares this number to the expected number of co-occurrences of word pairs which are randomly distributed across the whole corpus. Aletras and Stevenson (2013) proposes context vector representations for topic words w to generate the frequency of word co-occurrences within windows of ± 1 words surrounding all instances of w. They showed that NPMI (Bouma, 2009) has a larger correlation with human topic ratings compared to UCI and UMass. Additionally, NPMI takes into account the fact that some words are more common than others and adjusts the frequency of individual words accordingly (Lau et al., 2014). While NPMI is generally more sensitive to rare words and can handle small datasets, UMass focuses on the fast computation of coherence scores over large corpora. Stevens et al. (2012) showed that a smaller value of ϵ tends to yield better results than the default value of $\epsilon = 1$ used in the original paper since it emphasizes more the word combinations that are completely unattested. Röder et al. (2015) proposes a unifying framework of coherence measures that can be freely combined to form a configuration space of coherence definitions, allowing their main elementary components to be combined in the context of coherence quantification. For example, they propose the $\mathrm{C_V}$ metric, which uses a variation of NPMI to compute topic coherence over a sliding window of size N and adds a weight γ to assign more strength to more related words. According to (Campagnolo et al., 2022), the $\mathrm{C_V}$ metric is more sensitive to noisy information and dirty data than $\mathrm{C_{UMass}}$ and $\mathrm{C_{UCI}}$. Nikolenko (2016) and Schnabel et al. (2015) propose the $\mathrm{TC_{DWR}}$ metric based on the Distributed Word Representations

(DWR) (Mikolov et al., 2013b,a) which are better correlated to human judgment. Similarly, Ramrakhiyani et al. (2017) presents a coherence measure based on grouping topic words into buckets and using Singular Value Decomposition (SVD) and integer linear programming-based optimization to create coherent word buckets from the generated embedding vectors. Korenčić et al. (2018) proposes several topic coherence metrics based on topic documents rather than topic words. The approach essentially extracts topic documents, vectorizes them using several methods such as word embedding aggregation, and computes a coherence score based on the document vectors. Lund et al. (2019) proposes an automated evaluation metric for local-level topic models by introducing a task designed to elicit human judgment and reflect token-level topic quality. Bilal et al. (2021) investigate the evaluation of thematic coherence in microblog clusters and concludes that Text generation metrics (TGMs) proved most reliable, being less sensitive to time windows. Similar to this work, Stammbach et al. (2023) explores the use of LLMs in evaluating topic models and determining the optimal number of topics in large text collections.

3 Contextualised Topic Coherence

In this section we introduce Contextualized Topic Coherence (CTC), a new family of topic coherence metrics that benefit from the recent development of Large Language Models (LLM). We present two approaches. The first approach uses LLMs to compute contextualized estimates of the Pointwise Mutual Information (CPMI) between topic words. In the second approach, we use ChatGPT (OpenAI, 2022) to evaluate topic coherence by simulating to human-annotated evaluation methods.

3.1 Automated CTC

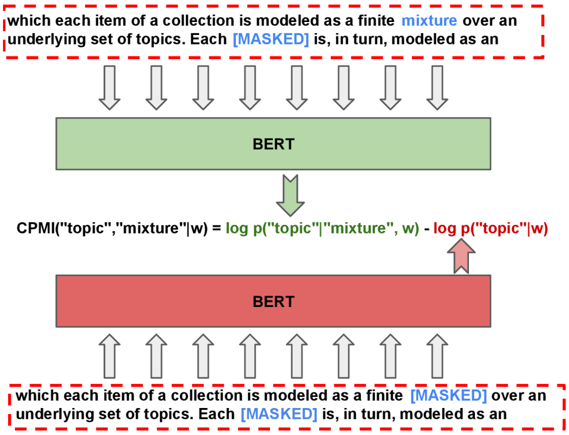

which each item of a collection is modeled as a finite mixture over an underlying set of topics. Each [MASKED] is, in turn, modeled as an
BERT
CPMI("topic","mixture"|w) = log p("topic"|"mixture", w) - log p("topic"|w)
BERT
which each item of a collection is modeled as a finite [MASKED] over an underlying set of topics. Each [MASKED] is, in turn, modeled as an

Figure 1: Calculating CPMI for two topic words in a segment of a document.

CPMI. Recent work by Hoover et al. (2021) uses conditional PMI estimates to analyze the relationship between linguistic and statistical word dependencies. They propose Contextualized PMI (CPMI) as a new method for estimating the conditional PMI between words *in context* using a pre-trained language model. The CPMI between two words w_i and w_j in a sentence s is defined by the following equation:

$$\mathrm{CPMI}(w_i, w_j \mid s) = \log \frac{p(w_i \mid s_{-w_i})}{p(w_i \mid s_{-w_{ij}})} \quad (1)$$

where s is a sentence, s_{-w_i} represents s with one masked word w_i (top in Figure 1) and $s_{-w_{ij}}$ is s with two masked words w_i and w_j (bottom in Figure 1). The conditional probability $p(w_i \mid s_{-w_{ij}})$ estimates the occurrence probability of w_i in $s_{-w_{ij}}$ based on a pre-trained masked language model (MLM) such as BERT.

We adopt CPMI to introduce a new automated Contextualized Topic Coherence (CTC) metric. Automated CTC estimates the the coherence of a topic by computing the CPMI value for each pair of topic words along a sliding window applied to the dataset. For this, the corpus is divided into a set of sliding window segments of length w and overlap k with previous and following segments to compute the average CPMI over all topic word pairs in all window segments:

$$\frac{1}{n * \binom{m}{2}} \sum_{i=1}^{n} \sum_{r=2}^{m} \sum_{s=1}^{r-1} \mathrm{CPMI}(w_i^r, w_i^s \mid c^u) \quad (2)$$

where $c^u \subset$ corpus D is a window segment with length of w that has k words overlapping with its adjacent window segments, n is the number of topics and m is the number of topic words.

3.2 Semi-automated CTC

Word Intrusion Task. Chang et al. (2009) proposed the *topic words intrusion task* to assess topic coherence by identifying a coherent latent category for each topic and discovering the words that do not belong to that category. In this task, human subjects detect *topic intruder words* to assess the quality of topic models and to measure a coherence score that assigns a low probability for intruder words to belong to a topic. We apply this idea by replacing humans with ChatGPT (OpenAI, 2022) answering to prompts (see Appendix B.1) which provide the topic words and ask for a category and intruder words.

Rating Task. The *topic rating task* consists in rating topics by their usefulness for a given task (for example, document search). While human topic ratings are expensive to produce, they serve as the gold standard for coherence evaluation (Röder et al., 2015). For example, Syed and Spruit (2017) uses human ratings to explore the coherence of topics generated by LDA topics across full texts and abstracts. Newman et al. (2010a) provides human annotators with a rubric and guidelines for judging whether a topic is useful or useless. The annotators evaluate a randomly selected subset of topics for their usefulness in retrieving documents on a given topic and score each topic on a 3-point scale, where 3=highly coherent and 1=useless (less coherent). Following (Newman et al., 2010a), Aletras and Stevenson (2013) presented topics without intruder words to Amazon Mechanical Turk to score them on a 3-point ordinal scale. Similar to the intrusion task, we adapt this method to ChatGPT by defining prompts (see Appendix B.2) which provide ChatGPT with the topic words and ask it to rate the usefulness of the various topic words for retrieving documents on a given topic. The $\text{CTC}_{\text{Rating}}$ for a topic model is obtained by the average sum of all ratings over all topics.

4 Experiments

In this section, we expect to observe that the baseline metrics (UCI, UMass, NPMI, C_V, DWR) rank topic models differently from CTC. We also expect CTC rankings favor interpretable topics and handle short text datasets more effectively than the baseline metrics (Doogan and Buntine, 2021; Hoyle et al., 2021). This implies that baseline metrics often yield high scores for incoherent topics, while conversely assigning low scores to well-interpretable topics. In contrast, CTC has a better model of language and can better evaluate topical similarity *as it would appear to a human reader*. Therefore, we expect to see that baseline metrics and CTC would differ at extremes of highest or lowest coherency.

4.1 Experimental setup

Datasets. The experiments incorporate two datasets including the 20Newsgroups dataset (Lang, 1995) and a collection of 17K tweets by Elon Musk published between 2017 and 2022 by (Raza, 2023).

Topic Models. The experiments involve six different topic models including Gibbs LDA (Griffiths and Steyvers, 2004), Embedded Topic Model (ETM) (Dieng et al., 2020), Adversarial-neural Topic Models (ATM) (Wang et al., 2019), Top2Vec (Angelov, 2020), and Contextualized Topic Model (CTM) (Bianchi et al., 2021), and BERTopic (Grootendorst, 2022).

Topic Coherence Metrics. The topics generated by the topic models are evaluated using the proposed Contextualized Topic Coherence (CTC) metrics, which are then compared to the well-established automated topic coherence metrics C_{V}, UCI, UMass, NPMI, and DWR. For CTC_{CPMI}, we segmented the 20Newsgroup and Elon Musk's Tweets datasets into chunks of 15 and 20 words, respectively, without intersections. We then extracted the CPMI for all word pairs in each segment using the pre-trained language models *bert-base-uncased* and *Tesla K80 15 GB GPU* from Google Colab (Bisong and Bisong, 2019). This pre-computing step took about 7 hours but allowed us to compute CTC_{CPMI} for any topic model in the order of a few seconds. For evaluating $\text{CTC}_{\text{Intrusion}}$ and $\text{CTC}_{\text{Rating}}$, we made a request for each topic to *ChatGPT* with *GPT 3.5 Turbo*, which cost less than a dollar for all the experiments.

4.2 Results

Tables 1 and 2 represent the results of the evaluation of the topic models obtained from the 20Newsgroup and Elon Musk's Tweets datasets, respectively, using CTC and the baseline metrics. The highest value for each metric is shown in bold to compare the models in terms of topic coherence metrics. The highest values for each metric within each topic model are noted in *italic* font. This helps us determine the optimal number of topics for all models except Top2Vec and BERTopic, which don't require this input parameter.

General observations. Before analyzing the results in Tables 1 and 2 in detail, we examine the relationship between the CTC metrics and the baseline metrics by performing Pearson's correlation coefficient analysis (Sedgwick, 2012) on the results from Tables 1 and 2 similar to (Doogan and Buntine, 2021). As shown in Figure 2a, for 20Newsgroup, the baseline metrics UCI and UMass are highly correlated with CPMI but not with $\text{CTC}_{\text{Rating}}$ and $\text{CTC}_{\text{Intrusion}}$, which are more correlated with the baseline measures NPMI and C_V and DWR (which are also highly correlated). On the other hand, for the short text EM Tweets dataset, Figure 2b shows that CPMI has a high correlation with all baseline methods, while $\text{CTC}_{\text{Intrusion}}$ and $\text{CTC}_{\text{Rating}}$ are completely independent of CPMI and the baseline measures.

Concerning our expectation that baseline metrics rank topic models differently from CTC metrics, Table 1 reports that the baseline metrics (except for UMass) point to Top2Vec while CTC metrics (except for $\text{CTC}_{\text{Rating}}$) point to ETM for achieving the highest scores. Similarly, Table 2 reports that the baseline metrics (except for C_V) point to ETM while CTC metrics (except for CTC_{CPMI}) point to CTM for achieving the highest scores. These contradictions between CTC and baseline metrics are aligned with our expectations and we will explore them with a meta-analysis of topics generated by these topic models and the scores they have received from CTC and baseline metrics.

Meta-analysis. To check the performance of different coherence metrics, we will compare the interpretability of their high and low-scoring topics. Note that CTC metrics observe contextual patterns between topic words, and therefore, we expect them to provide more consistent coherence scores according to the interpretability of the generated topics for all topic models.

To verify the consistency of some representative scores in Table 1, we examine the topics for 20 Newsgroup generated by Top2Vec, which have high and low baseline metrics scores, and ETM, which have high and low CTC metrics scores. Table 3 compares the top-2 and bottom-2 topics ranked by C_V and CTC_{CPMI}. The choice of these metrics is motivated by our correlation analysis (see Figure 2a in Appendix C), which has the least correlation among CTC and baseline metrics in CTC_{CPMI} and C_V. First, we notice that the top-2 topics returned by C_V for Top2Vec are not readily interpretable but are statistically meaningful: *dsl, geb, cadre, shameful, jxp* are fragments of an email signature that occurs 82 times, while *tor, nyi, det, chi, bos* are abbreviations for hockey teams. This is not surprising, since Top2Vec produces what we call "trash topics", which is a common problem for clustering-based topic models that cannot handle so-called "trash clusters" (Giannotti et al., 2002). CTC_{CPMI} returns a more coherent ranking for Top2Vec (the top 2 topics appear coherent, while the bottom topics are incoherent for human evaluation). This supports our assumption that traditional topic coherence metrics such as C_V fail to evaluate neural topic models and, in this case, even give the highest scores to trash topics. This happens because they only consider the syntactic co-occurrence of words in a window of text and cannot observe the underlying relationship between topic words. CTC_{CPMI}, on the other hand, can detect these trash topics and scores them more accurately because it is supported by LLMs that have rich information about linguistic dependencies between topic words. Therefore, CTC_{CPMI} also might be

Table 1: Scores of Topic Coherence Metrics on 20Newsgroup dataset.

Topic Models		Baseline Metrics					CTC Metrics		
	#T	UCI	UMass	NPMI	C_V	DWR	Rating	Intrusion	CPMI
Gibbs LDA (2003)	20	*0.260*	*-2.338*	*0.043*	*0.512*	*0.211*	*1.3*	0.225	*9.92*
	50	-0.121	-2.771	0.023	0.479	0.191	1.16	0.220	5.99
	100	-0.690	-3.030	0.002	0.450	0.149	1.14	*0.267*	3.25
ETM (2020)	20	*0.478*	-2.08	*0.067*	*0.563*	0.292	0.7	***0.452***	19.16
	50	0.380	***-1.903***	0.054	0.532	*0.330*	1.22	0.348	20.35
	100	0.351	-1.962	0.049	0.522	0.312	*1.23*	0.41	***22.58***
ATM (2019)	20	-1.431	-3.014	-0.059	0.338	*0.151*	0.92	0.305	0.03
	50	-0.940	-2.902	-0.046	0.342	0.077	*1.15*	0.275	0.18
	100	*-0.735*	*-2.741*	*-0.032*	*0.362*	0.053	1.12	*0.340*	*1.72*
CTM (2021)	20	-1.707	-4.082	0.005	*0.601*	*0.268*	1.25	0.385	*5.93*
	50	*-0.724*	*-3.008*	*0.046*	0.590	0.236	*1.56*	0.380	7.02
	100	-0.926	-3.118	0.027	0.561	0.210	1.31	*0.392*	6.16
Top2Vec (2020)	85	***0.910***	*-2.449*	***0.192***	***0.785***	***0.473***	***1.670***	*0.399*	*3.77*
BERTopic (2022)	145	*-1.023*	*-5.033*	*0.098*	*0.681*	*0.309*	*1.517*	*0.359*	*2.91*

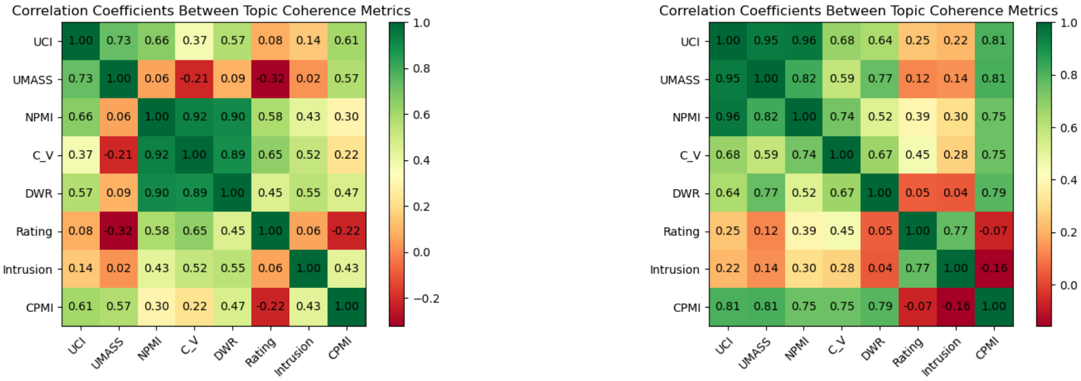
Table 2: Scores of Topic Coherence Metrics on Elon Musk's Tweets dataset

Topic Models		Baseline Metrics					CTC Metrics		
	#T	UCI	UMass	NPMI	C_V	DWR	Rating	Intrusion	CPMI
Gibbs LDA (2003)	10	*-0.441*	*-3.790*	*0.016*	*0.498*	*0.838*	*1.6*	0.29	*2.19*
	20	-1.834	-5.415	-0.049	0.395	0.798	1.5	0.225	1.04
	30	-3.068	-6.390	-0.099	0.336	0.783	1.466	*0.33*	0.86
ETM (2020)	10	***0.205***	-3.209	***0.051***	*0.560*	0.952	1.1	*0.24*	***5.41***
	20	0.155	***-3.079***	0.028	0.538	0.974	*1.433*	0.233	4.48
	30	0.025	-3.215	0.022	0.515	***0.978***	1.05	0.195	4.30
ATM (2019)	10	-9.021	-12.859	-0.324	*0.364*	0.730	*1.2*	0.211	-0.004
	20	-7.967	-11.770	-0.283	0.343	0.694	1.1	0.177	*0*
	30	*-7.278*	*-11.301*	*-0.258*	0.350	*0.753*	0.933	*0.214*	-0.03
CTM (2021)	10	*-2.614*	*-7.049*	*-0.030*	***0.580***	*0.888*	***2.0***	***0.439***	1
	20	-3.720	-8.336	-0.070	0.534	0.880	1.45	0.185	*3.04*
	30	-3.589	-8.063	-0.064	0.573	0.873	1.766	0.276	2.56
Top2Vec (2020)	164	*-6.272*	*-10.536*	*-0.152*	*0.401*	*0.847*	*1.481*	*0.274*	*2.08*
BERTopic (2022)	217	*-4.131*	*-11.883*	*-0.020*	*0.432*	*0.541*	*1.539*	*0.276*	*1.52*

a good measure to filter "trash topics" obtained by some cluster-based topic model. The second observation in Table 3 is that all eight topics returned for ETM are coherent. This is because ETM, which is a semantically-enabled probabilistic topic model, produces decent topics that are overall highly ranked by CTC_{CPMI} (see Figure 3b in Appendix C).

In the same way we verify the consistency of some representative scores in Table 2 by checking the interpretability of topics for Elon Musk's tweets generated by ETM, which has high baseline scores, and by CTM, which has high CTC scores. These metrics are among those with the lowest correlation between CTC and baseline metrics (see Figure 2b in Appendix C). We compare the top 2 and bottom 2 topics ranked by NPMI and $\text{CTC}_{\text{Rating}}$ shown in Table 4.

A notable finding for CTM topics is that topics ranked highest by the $\text{CTC}_{\text{Rating}}$ metric tend to be more interpretable compared to those ranked highest by NPMI. Similarly, topics ranked lowest by the $\text{CTC}_{\text{Rating}}$ metric tend to be less interpretable compared to those ranked lowest by NPMI. These observations also apply to ETM, as the $\text{CTC}_{\text{Rating}}$ metric is not affected by the scarcity of short text records. This is because $\text{CTC}_{\text{Rating}}$ is complemented by a chatbot that mitigates the impact of limited data availability. It is also interesting to note that the topics generated by CTM are overall more interpretable and coherent than those generated by ETM. This demonstrates the validity of $\text{CTC}_{\text{Rating}}$ and $\text{CTC}_{\text{Intrusion}}$ over baseline metrics, as we observed in Table 2. It also reveals the superiority of CTM over ETM (see Figure 3d in Appendix C) for short text datasets as a result of



(a) 20Newsgroup

(b) Elon Musk Tweets

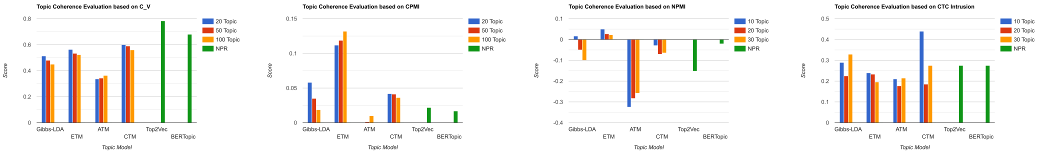
Figure 2: Pearson's correlation coefficient on CTC and baseline

Table 3: Top-2 and bottom-2 topics of ETM$^{(100)}$ and Top2Vec on 20Newsgroup

Topic Model	Ranked By	Topics	C_V	CPMI
ETM$^{(100)}$ (2020)	Highest C_V	god, christian, people, believe, jesus	0.740	0.017
		drive, card, scsi, disk, mb,	0.739	0.037
	Lowest C_V	book, number, problem, read, call	0.369	0.018
		line, use, power, bit, high	0.458	0.018
	Highest CPMI	year, time, day, one, ago, week	0.559	0.709
		game, year, team, player, play	0.706	0.242
	Lowest CPMI	new, number, also, well, call, order, used	0.340	-0.007
		people, right, drug, state, world, country	0.529	-0.002
Top2Vec (2020)	Highest C_V	dsl, geb, cadre, shameful, jxp	0.995	0.009
		tor, nyi, det, chi, bos	0.989	0.012
	Lowest C_V	hacker, computer, privacy, uci, ethic	0.255	-0.0001
		battery, acid, charged, storage, floor	0.344	0.006
	Highest CPMI	mailing, list, mail, address, send	0.792	0.154
		icon, window, manager, file, application	0.770	0.076
	Lowest CPMI	lc, lciii, fpu, slot, nubus, iisi	0.853	-0.004
		ci, ic, incoming, gif, edu	0.644	-0.002

Table 4: Top-2 and bottom-2 topics of ETM$^{(30)}$ and CTM$^{(30)}$ on Elon Musk's Tweets

Topic Model	Ranked By	Topics	NPMI	Rating	Intrusion
CTM$^{(30)}$ (2021)	Highest NPMI	erdayastronaut, engine, booster, starship, amp	0.122	3	0.1
		year, week, next, month, wholemarsblog	0.057	2	0.1
	Lowest NPMI	transport, backup, ensure, installed, transaction	-0.480	2	0.1
		achieving, transition, late, transport, precision	-0.459	1	0.1
	Highest Rating	tesla, rt, model, car, supercharger	-0.152	3	0.5
		spacex, dragon, launch, falcon, nasa	-0.283	3	0.4
	Lowest Rating	ppathole, soon, justpaulinelol, yes, sure	-0.330	1	0.5
		achieving, transition, late, transport, precision	-0.459	1	0.1
ETM$^{(30)}$ (2020)	Highest NPMI	amp, time, people, like, would, many	0.001	2	0.7
		engine, booster, starship, heavy, raptor	-0.023	2	0.1
	Lowest NPMI	amp, rt, tesla, im, yes	-0.283	1	0.1
		amp, tesla, year, twitter, work	-0.228	1	0.1
	Highest Rating	amp, twitter, like, tesla, dont	-0.186	2	0.8
		amp, time, people, like, would	0.001	2	0.7
	Lowest Rating	amp, tesla, year, twitter, work	-0.228	1	0.1
		amp, tesla, one, like, time	-0.204	1	0.1



(a) 20Newsgroup | C_V

(b) 20Newsgroup | CPMI

(c) Twitter | NPMI

(d) Twitter | Intrusion

Figure 3: Comparison Between Topic Models based on Topic Coherence Evaluation

Table 5: Top-5 topics among the topics generated by Gibbs LDA, DVAE and ETM on NYT News

Top-5 Sorted by	Model	Topic	Scores		
			C_V	Human	CTC
C_V	DVAE	inc, 9mo, earns, otc, qtr, rev	0.98	1.2	0.9
	DVAE	inc, 6mo, earns, otc, rev, qtr	0.98	1.2	1.3
	DVAE	inc, otc, qtr, earns, rev, 6mo	0.97	1.3	0.8
	DVAE	arafat, hamas, gaza, palestinians, west_bank	0.97	2.1	1.5
	DVAE	condolences, mourns, mourn, board_of_directors, heartfelt, deepest	0.97	0.6	1.3
Human Score	Gibbs LDA	film, theater, movie, play, director, films	0.73	3	2.7
	DVAE	skirts, dresses, chanel, couture, fashion	0.91	3	1.3
	DVAE	tenants, tenant, zoning, rents, landlords, developers	0.86	3	1.2
	DVAE	paintings, sculptures, galleries, picasso, sculpture, drawings,	0.91	2.9	2.1
	DVAE	television, network, news, cable, nbc, year, cbs	0.68	2.8	1.9
CTC	Gibbs LDA	film, theater, movie, play, director, films	0.73	3	2.7
	ETM	court, judge, law, case, federal, lawyer, trial	0.80	2.8	2.6
	Gibbs LDA	court, law, judge, case, state, federal, legal,	0.72	2.6	2.2
	Gibbs LDA	music, dance, opera, program, work, orchestra, performance	0.73	1.1	2.1
	ETM	film, movie, story, films, directed, movies, star, character	0.79	2.7	2.1

a contextualized element in its architecture.

5 Human Evaluation

The goal of automated topic coherence metrics is to accurately approximate human judgment on topics without the need for expensive, time-consuming studies that require multiple annotators to avoid bias. In this section we compare the proposed metric with a human evaluation data provided by Hoyle et al. (2021). This data includes human evaluation scores (intrusion and ranking) for 50 topics generated by three topic models (Gibbs LDA (McCallum, 2002), DVAE (Srivastava and Sutton, 2017), and ETM (Dieng et al., 2020)) applied on the (New York Times) dataset. We evaluate the generated topics with CTC_{CPMI}, $\text{CTC}_{\text{intrusion}}$ and $\text{CTC}_{\text{ranking}}$, which are comparable to human intrusion and human ranking.

As shown in Table 6, human evaluators tend to see little quantifiable difference between Gibbs LDA and DVAE, while traditional metrics show pronounced differences. In contrast, we find that CTC metrics more closely match human preferences (or lack thereof). It is possible that this result is simply due to a miscalibration of relative scores. We also report Spearman's Rank Correlation (Myers and Sirois, 2004) results to assess the strength and direction of the monotonic relationship between the ranking of topics in each metric. The CTC metrics have an overall higher correlation with human ratings than the baseline metrics (see Figure 4 in Appendix C).

Table 6: Topic Coherence Scores of Gibbs LDA, DVAE, ETM on NYT News

		Topic Models (T = 50)		
Metrics		Gibbs LDA	DVAE	ETM
Baseline	UCI	1.42	**2.43**	1.01
	UMass	-7.6	-15	**-7.4**
	C_V	0.69	**0.84**	0.60
	NPMI	0.15	**0.25**	0.11
Human	Intrusion	0.71	**0.74**	0.64
	Rating	**2.66**	2.48	2.38
CTC	Intrusion	**2.12**	2.05	2.06
	Rating	0.62	**0.67**	0.64
	CPMI	**4.18**	0.61	3.72

We also can examine and compare different coherence metrics by analysing the topic words of high and low scoring topics. As shown in Tables 5 and 7, C_V generates top topics which probably would not be chosen by a human. For example, the topic *inc, 9mo, earns, otc, qtr, rev* gets the highest score, even though it has little clear interpretability. On the other hand, CTC metrics score topics relative to their contextual

Table 7: Bottom-5 topics among the topics generated by Gibbs LDA, DVAE and ETM on NYT News

Botton-5 Sorted by	Model	Topic	Scores		
			C_V	Human	CTC
C_V	DVAE	spade, derby, belmont, colt, spades, dummy, preakness	0.23	1.5	0.4
	ETM	like, making, important, based, strong, including, recent	0.35	2	0.3
	ETM	time, half, center, open, away, place, high	0.37	1.6	0.2
	ETM	today, group, including, called, led, known, began, built, early,	0.37	2	0.3
	Gibbs LDA	people, editor, time, world, good, years, public, long,	0.37	0.1	1.1
Human Score	Gibbs LDA	people, editor, time, world, good, years, public,	0.37	0.1	1.1
	ETM	week, article, page, march, tuesday, june, july	0.57	0.4	1.3
	Gibbs LDA	street, tickets, sunday, avenue, information, free	0.75	0.4	0.3
	ETM	new_york, yesterday, director, manhattan, brooklyn, received	0.49	0.4	1
	Gibbs LDA	bedroom, room, bath, taxes, year, market, listed, kitchen, broker	0.72	0.4	1.3
CTC	Gibbs LDA	city, mayor, state, new_york, new_york_city, officials	0.61	2.5	0.1
	ETM	power, number, control, according, increase, large	0.44	0.9	0.2
	Gibbs LDA	officials, board, report, union, members, agency, yesterday	0.51	0.8	0.3
	ETM	time, half, center, open, away, place, high, day, run	0.37	1.2	0.3
	ETM	net, share, inc, earns, company, reports, loss, lead	0.73	1.8	0.3

relationship and are very close to human scores. For example, the topic *film, theater, movie, play, director, movies* receives the highest score by both CTC and human scoring.

6 Conclusion

This paper introduces a new family of topic coherence metrics called Contextualized Topic Coherence Metrics (CTC) that benefits from the recent development of Large Language Models (LLM). CTC includes two approaches that are motivated to offer flexibility and accuracy in evaluating neural topic models under different circumstances. Our results show that automated CTC outperforms the baseline metrics on large-scale datasets while semi-automated CTC outperforms the baseline metrics on short-text datasets. After a comprehensive comparison between recent neural topic models and dominant classical topic models, our results indicate that some neural topic models which optimize traditional topic coherence metrics, often receive high scores for topics that are overly sensitive to idiosyncrasies such as repeated text, and lack face validity. We show with our experiments that CTC is not susceptible to being deceived by these meaningless topics by leveraging the ability of LLMs to better model human expectations for language and evaluate topics within and outside their contextual framework.

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Limitations

CTC metrics come with several limitations, such as latency, accuracy, and the potential for biased results. For instance, CPMI can be a time-consuming process, as it involves running all sentences through LLMs and calculating word co-occurrences for every pair of words across all topics. Additionally, the results for Rating and Intrusion may vary with each query to LLMs. Therefore, it is necessary to configure the LLM's temperature and iterate through multiple queries to obtain normalized values. Furthermore, it's important to be aware that LLMs can exhibit bias, and their utilization for topic coherence evaluation could potentially perpetuate such biases.

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A Automated Coherence Metrics

Topic Models were initially evaluated with held-out perplexity as an automated metric (Blei et al., 2003). Perplexity quantifies how well a statistical model predicts a sample of unseen data and is computed by taking the inverse probability of the test set, normalized by the number of words in the dataset. According to (Chang et al., 2009), perplexity has been found to be inconsistent with human interpretability. As a result, the field shifted towards adopting automated topics coherence metrics that rely on word co-occurrence-based methods like Point-wise Mutual Information (PMI) (Cover, 1999).

A.1 Definition

As defined as follows, Topic coherence over PMI ($\mathrm{TC}_{\mathrm{UCI}}$) is defined as the average of the $\log_2$ ratio of co-occurrence frequency of word w_i^r and w_i^s within a given topic i.

$$\mathrm{TC}_{\mathrm{UCI}} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{\binom{m}{2}}\sum_{r=2}^{m}\sum_{s=1}^{r-1}\mathrm{PMI}(w_i^r, w_i^s) \quad (3)$$

with

$$\mathrm{PMI}(w^i, w^j) = \log_2\frac{P(w^i, w^j)+\epsilon}{P(w^i)P(w^j)} \quad (4)$$

where n is the number of topics with m topic words and PMI represents the pointwise mutual information between each pair of words (w_i^r and w_i^s) in the topic i. PMI is computed by taking the logarithm of the ratio of the joint probability of two words $P(w_i^r, w_i^s)$ appearing together to the individual probabilities of the words $P(w_i^r)$, $P(w_i^s)$ occurring separately. Note that $\epsilon = 1$ is added to avoid the logarithm of zero.

On the other hand, UMass (Mimno et al., 2011) computes the co-document frequency of word w_i^r and w_i^s divided by the document frequency of word w_i^s.

$$\mathrm{UMass}(w_i^r, w_i^s) = \log\frac{D(w_i^r, w_i^s)+\epsilon}{D(w_i^s)} \quad (5)$$

where n and m are the numbers of topics and topic words respectively. The smoothing parameter ϵ was initially introduced to be equal to one and avoid the logarithm of zero.

Similarly, (Aletras and Stevenson, 2013) proposes context vectors for each topic word w to generate the frequency of word co-occurrences within windows of ± 1 words surrounding all instances of w.

$$\mathrm{NPMI}(w_i^r, w_i^s) = \frac{\log_2\frac{P(w_i^r, w_i^s)+\epsilon}{P(w_i^r)P(w_i^s)}}{-\log_2(P(w_i^r, w_i^s)+\epsilon)} \quad (6)$$

(Röder et al., 2015) proposes C_V, which is a variation of NPMI.

$$\mathrm{C_V}(w_i^r, w_i^s) = \mathrm{NPMI}^{\gamma}(w_i^r, w_i^s) \quad (7)$$

One way to estimate $\mathrm{TC}_{\mathrm{DWR}}$ is to compute the average pairwise cosine similarity between word vectors in a topic as follows.

$$\mathrm{DWR}(w_i^r, w_i^s) = \frac{w_i^r \cdot w_i^s}{\|w_i^r\| \cdot \|w_i^s\|} \quad (8)$$

B LLM Prompts

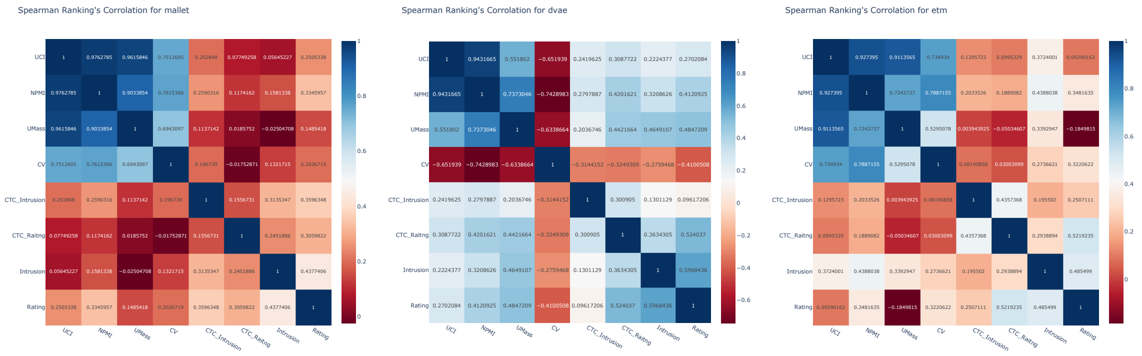
In this section, we present LLM prompts used in our experiments. The descriptions of the prompts for the ratings and intrusion task are as follows.

B.1 Intrusion

System prompt: *I have a topic that is described by the following keywords: [topic-words]. Provide a one-word topic based on this list of words and identify all intruder words in the list with respect to the topic you provided. Results be in the following format: topic: <one-word>, intruders: <words in a list>*

The number of intrusion words ($|I_i|$) returned by chatbot for each topic i, is used to define $\mathrm{CTC}_{\mathrm{Intrusion}}$ as follows:

$$\mathrm{CTC}_{\mathrm{Intrusion}} = \sum_{i=1}^{n}\frac{1-\frac{|I_i|}{m}}{n} \quad (9)$$



(a) Gibbs LDA (b) DVAE (c) ETM

Figure 4: Spearman's rank correlation coefficients between evaluation metrics for three topic models

where n is the number of topics and m is the number of topic words.

B.2 Rating

System prompt: *I have a topic that is described by the following keywords: [topic-words]. Evaluate the interpretability of the topic words on a 3-point scale where 3 = "meaningful and highly coherent" and 0 = "useless" as topic words are usable to search and retrieve documents about a single particular subject. Results be in the following format: score: <score>*

B.3 Normalized CPMI

To improve comparability, we also propose a normalized version of CPMI that extend its generalizability and allows to mitigate potential biases that may arise due to specific dataset characteristics or idiosyncrasies. Additionally, it facilitates threshold determination and provides a consistent scale that allows researchers to set thresholds based on desired coherence levels, ensuring the metric is effectively utilized in practical applications.

B.3.1 Definition

Given a set of n topics TM $\mapsto \{t_1, t_2, \dots, t_n\}$ with m words $t_i \mapsto \{w^i_1, w^i_2, \dots, w^i_m\}$ as an output of topic model TM on the corpus of e documents $D = \{d_1, d_2, \dots, d_e\}$, the CTC based on Normalized CPMI (NCPMI) called CTC$_{\text{NCPMI}}$ is defined as follows.

$$\frac{1}{e * n * m} \sum_{d=1}^{e} \sum_{i=1}^{n} \sum_{j=1}^{m} \text{NCPMI}(w^i_j, t^i \mid c^d) \tag{10}$$

while NCPMI$(w^i_j, t^i \mid c^d)$ is:

$$\frac{log \frac{P(w^i_j|c^d_{-w^i_j})}{P(w^i_j|c^d_{-t^i})}}{-log(P(w^i_j \mid c^d_{-w^i_j}) \times P(t^i \mid c^d_{-t^i}))} \tag{11}$$

where P is an estimate for the probability of words given context based on language model LM. The $c^d_{-w_i}$ is the document d with word w_i masked, and $c^d_{-t_j}$ is the document d with words of topic t^i masked.

C Correlation Study

Pearson correlation is a statistical measure used to assess the degree of linear association between sets of data. As shown Figure 2, we applied this method to the results of topic coherence metrics on the topic models to evaluate how closely related or similar the quality of topics generated by these models is. A high positive Pearson correlation coefficient indicates that the topic models produce similar results in terms of topic coherence, suggesting that they are consistent and reliable. Conversely, a low or negative correlation suggests inconsistency or divergence in the quality of topics generated by the different models.

On the other hand, Spearman's rank correlation coefficient is a statistical measure used to assess the strength and direction of the monotonic relationship between sets of data. As show in Figure 4, we applied this method to evaluation topic coherence metrics for human evaluation to determine if there is a consistent ranking of these models in terms of their performance across different metrics. A high positive Spearman's rank correlation coefficient suggests that the rankings of the three models across the evaluation metrics are similar, indicating consistency in their performance. Conversely, a low or negative correlation suggests variability in the rankings, indicating that different metrics may lead to different model preferences.

D Code

CTC is implemented as a service for researchers and engineers who aim to evaluate and fine-tune their topic models. The source code of this python package is provided in *./ctc* and a notebook named *example.ipynb* is prepared to explain how to use this python package as follows.

D.0.1 Automated CTC

```python
from ctc.main import Auto_CTC
#initiating the metric
evalu=Auto_CTC(segments_length=15, min_segment_length=5, segment_step=10,device="mps")

# segmenting the documents
docs=documents
evalu.segmenting_documents(docs)

# creating cpmi tree including all co-occurence values between all pairs of words
evalu.create_cpmi_tree()
#evalu.load_cpmi_tree()

# topics=[["game","play"],["man","devil"]] for instance
evalu.ctc_cpmi(topics)
```

D.0.2 Semi-automated CTC

```python
from ctc.main import Semi_auto_CTC

openai_key="YOUR OPENAI KEY"

y=Semi_auto_CTC(openai_key, topics)

y.ctc_intrusion()

y.ctc_rating()
```