ATTENTION-LIKELIHOOD RELATIONSHIP IN TRANSFORMERS

Valeria Ruscio * **Valentino Maiorca** **Fabrizio Silvestri**

Sapienza University of Rome

ABSTRACT

We analyze how large language models (LLMs) represent out-of-context words, investigating their reliance on the given context to capture their semantics. Our likelihood-guided text perturbations reveal a correlation between token likelihood and attention values in transformer-based language models. Extensive experiments reveal that unexpected tokens cause the model to attend less to the information coming from themselves to compute their representations, particularly at higher layers. These findings have valuable implications for assessing the robustness of LLMs in real-world scenarios. Fully reproducible codebase at `https://github.com/Flegyas/AttentionLikelihood`.

1 INTRODUCTION

Transformers, introduced by Vaswani et al. (2017), are the state-of-the-art architecture for language models that rely on self-attention to capture the contextual relationships between tokens in a sentence. While previous research has explored various aspects of the attention mechanism in transformers, such as specialized attention heads and the informative nature of attention weights (Vig & Belinkov, 2019; Kovaleva et al., 2019; Clark et al., 2019), other studies inquire whether attention alone can fully explain the transformer's output (Wiegreffe & Pinter, 2019; Jain & Wallace, 2019; Bibal et al.). Despite this previous work, there is still much to learn about the practical workings of the attention mechanism in transformers. In this study, we investigate the impact of token likelihood, i.e., the modeled probability distribution of a token, on the self-attention mechanism in transformers. Our findings show that tokens with a higher likelihood value receive a correspondingly higher attention value, indicating that the model is relying on the token itself to understand its semantics. However, when out-of-context (i.e., low-likelihood) tokens are encountered, the model redirects its attention to the surrounding context *uniformly*, suggesting that the attention mechanism in transformers handles outliers by nullifying their information. These insights can foster the development of more robust and accurate language models, enhancing their ability to handle unexpected input.

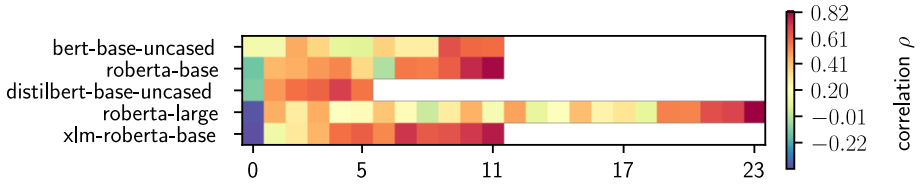

Figure 1: The correlation ρ between likelihood and token attention for various models and layers.

2 METHODOLOGY

We conduct a series of likelihood-guided perturbation experiments to investigate the impact of a token's likelihood on the self-attention mechanism in transformers. Let M be a frozen autoencoder transformer model (e.g., BERT (Devlin et al., 2019)), and let $\mathcal{S}$ be a set of sentences. We are

*Corresponding author: valeria.ruscio@uniroma1.it

Table 1: The table shows, for both datasets, the mean: token attention $\mathbf{A_{ii}}$, correlation ρ and likelihood L_s. The Mann-Whitney U (MWU) is tested between the sentence attentions of the two.

		Original ($\mathcal{S}$)			**Perturbed** ($\hat{\mathcal{S}}$)			**MWU**
encoder	**layer**	$\bar{\mathbf{A}}_{\mathbf{ii}}$	$\bar{L}_s$	$\bar{\rho}$	$\bar{\hat{A}}_{ii}$	$\bar{\hat{L}}_s$	$\bar{\hat{\rho}}$	**p-value**
BERT	9	0.075	0.664	0.095	0.063	0.096	0.643	0.52
RoBERTa base	11	0.124	0.938	0.247	0.043	0.072	0.802	0.54
XLM-R	11	0.132	0.943	0.332	0.051	0.017	0.767	0.48
RoBERTa large	23	0.134	0.947	0.183	0.046	0.055	0.823	0.56
DistilBERT	4	0.065	0.785	0.033	0.045	0.017	0.688	0.55

interested in two different outputs of M applied to each $s \in \mathcal{S}$: **i)** the likelihood L_{s_i} of token s_i at position i in s as the conditional probability $P(s_i|s, M)$; **ii)** the attention matrices $\mathbf{A}^{(l)}$ for each multi-head attention layer l of M. Note that we aggregate the outputs of the multiple attention heads in each layer into a single one via mean pooling. After computing likelihood and attention on the original set $\mathcal{S}$, we formulate a likelihood-based perturbation on its sentences as follows: for each sentence $s \in S$, we select a token s_i and replace it with a "perturbed" token $\hat{s_i}$, such that $L_{\hat{s}_i} \ll L_{s_i}$. We then apply M on this perturbed set $\hat{\mathcal{S}}$ to generate the perturbed likelihoods and attention matrices $\hat{\mathbf{A}}^(l)$. We define the *token attention* of the token s_i at layer l as $\mathbf{A}_{ii}^{(l)}$. Similarly, the *sentence attention* is the concatenation of all the other attention weights on the i-th row of $\mathbf{A}$: $\oplus_{i \neq j} \mathbf{A}_{i,j}^{(l)}$. We compute them for both the original sentences $\mathcal{S}$ and the perturbed ones $\hat{\mathcal{S}}$. This methodology enables us to investigate the impact of a token's likelihood on the self-attention mechanism in transformers and probe the model's ability to adapt to unexpected input at its different layers while maintaining a controlled experimental setup by perturbing each sentence once and only one token per sentence.

3 EXPERIMENTS

We conduct experiments on a dataset $\mathcal{S}$ consisting of around 20k English sentences extracted from WordNet (Miller, 1992). Our analysis involves five transformer models, namely RoBERTa (Liu et al., 2019b) (*base* and *large* versions), BERT (Devlin et al., 2019) and DistilBERT (Sanh et al., 2019) (*base uncased* versions), and XLM-R (Conneau et al., 2020). To investigate the relationship between token likelihood and token attention, we use the Spearman correlation metric on both the original and the perturbed dataset. We report the results of our experiments in table 1. The complete version can be found in the appendix along with additional dataset details. Our findings reveal a **strong correlation** between token likelihood and attention values. Specifically, the token's attention decreases significantly when its likelihood is lowered, indicating that when the model encounters an unexpected token, it shifts its focus from the token to the context to compute its representation. We observe that the attention previously directed to the token is then distributed uniformly to the rest of the sentence, as confirmed by the results of the Mann-Whitney U test (McKnight & Najab, 2010) applied between the attention distributions. Furthermore, we observe that the attention changes due to likelihood-guided perturbations are relevant across most model layers. However, the correlation values are stronger in the latest layers that encode more abstract semantic features Rogers et al. (2020); Liu et al. (2019a). In contrast, in the first layers, the model relies more on the token itself to understand its meaning (Vig & Belinkov, 2019), even when perturbed.

4 CONCLUSION

Our study thoroughly analyzed the link between token likelihood and the self-attention mechanism in transformers, finding a strong statistical correlation between them. This can be seen as a transformer strategy to handle out-of-context words since it redirects its focus from the unlikely token to the context to grasp its semantics, especially at deeper attention layers. Future research could explore the implications of these findings on downstream tasks, enhance language models' robustness, and investigate this phenomenon in different domains, such as ViTs (Dosovitskiy et al., 2020). This could further our understanding of the self-attention mechanism and its application to other fields.

ACKNOWLEDGEMENTS

This work is supported by the ERC Grant no.802554 "SPECGEO" and PRIN 2020 project no.2020TA3K9N "LEGO.AI"

URM STATEMENT

The first author (VR) meets the URM criteria of ICLR 2023 Tiny Papers Track.

REFERENCES

Adrien Bibal, Rémi Cardon, David Alfter, Rodrigo Wilkens, Xiaoou Wang, Thomas François, and Patrick Watrin. Is attention explanation? an introduction to the debate.

Steven Bird, Ewan Klein, and Edward Loper. *Natural Language Processing with Python: Analyzing Text with the Natural Language Toolkit*. O'Reilly Media, Inc., 2009.

Kevin Clark, Urvashi Khandelwal, Omer Levy, and Christopher D. Manning. What does BERT look at? an analysis of BERT's attention. In *Proceedings of the 2019 ACL Workshop BlackboxNLP: Analyzing and Interpreting Neural Networks for NLP*, pp. 276–286, Florence, Italy, 2019. Association for Computational Linguistics. doi: 10.18653/v1/W19-4828. URL https://aclanthology.org/W19-4828.

Alexis Conneau, Kartikay Khandelwal, Naman Goyal, Vishrav Chaudhary, Guillaume Wenzek, Francisco Guzmán, Edouard Grave, Myle Ott, Luke Zettlemoyer, and Veselin Stoyanov. Unsupervised cross-lingual representation learning at scale. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pp. 8440–8451, Online, 2020. Association for Computational Linguistics. doi: 10.18653/v1/2020.acl-main.747. URL https://aclanthology.org/2020.acl-main.747.

Jacob Devlin, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. BERT: Pre-training of deep bidirectional transformers for language understanding. In *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long and Short Papers)*, pp. 4171–4186, Minneapolis, Minnesota, 2019. Association for Computational Linguistics. doi: 10.18653/v1/N19-1423. URL https://aclanthology.org/N19-1423.

Alexey Dosovitskiy, Lucas Beyer, Alexander Kolesnikov, Dirk Weissenborn, Xiaohua Zhai, Thomas Unterthiner, Mostafa Dehghani, Matthias Minderer, Georg Heigold, Sylvain Gelly, Jakob Uszkoreit, and Neil Houlsby. An image is worth 16x16 words: Transformers for image recognition at scale. *ArXiv preprint*, abs/2010.11929, 2020. URL https://arxiv.org/abs/2010.11929.

Sarthak Jain and Byron C. Wallace. Attention is not Explanation. In *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long and Short Papers)*, pp. 3543–3556, Minneapolis, Minnesota, 2019. Association for Computational Linguistics. doi: 10.18653/v1/N19-1357. URL https://aclanthology.org/N19-1357.

Olga Kovaleva, Alexey Romanov, Anna Rogers, and Anna Rumshisky. Revealing the dark secrets of BERT. In *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, pp. 4365–4374, Hong Kong, China, 2019. Association for Computational Linguistics. doi: 10.18653/v1/D19-1445. URL https://aclanthology.org/D19-1445.

Ruslan Kuprieiev, skshetry, Dmitry Petrov, Peter Rowlands, Paweł Redzyński, Casper da Costa-Luis, Alexander Schepanovski, Gao, David de la Iglesia Castro, Ivan Shcheklein, Batuhan Taskaya, Jorge Orpinel, Fábio Santos, Dave Berenbaum, daniele, Ronan Lamy, Aman Sharma, Zhanibek Kaimuldenov, Dani Hodovic, Nikita Kodenko, Andrew Grigorev, Earl, Nabanita Dash, George Vyshnya, maykulkarni, Max Hora, Vera, and Sanidhya Mangal. Dvc: Data version control - git for data & models, 2023. URL https://doi.org/10.5281/zenodo.7646429.

Quentin Lhoest, Albert Villanova del Moral, Yacine Jernite, Abhishek Thakur, Patrick von Platen, Suraj Patil, Julien Chaumond, Mariama Drame, Julien Plu, Lewis Tunstall, Joe Davison, Mario Šaško, Gunjan Chhablani, Bhavitvya Malik, Simon Brandeis, Teven Le Scao, Victor Sanh, Canwen Xu, Nicolas Patry, Angelina McMillan-Major, Philipp Schmid, Sylvain Gugger, Clément Delangue, Théo Matussière, Lysandre Debut, Stas Bekman, Pierric Cistac, Thibault Goehringer, Victor Mustar, François Lagunas, Alexander Rush, and Thomas Wolf. Datasets: A community library for natural language processing. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing: System Demonstrations*, pp. 175–184, Online and Punta Cana, Dominican Republic, 2021. Association for Computational Linguistics. URL https://aclanthology.org/2021.emnlp-demo.21.

Nelson F. Liu, Matt Gardner, Yonatan Belinkov, Matthew E. Peters, and Noah A. Smith. Linguistic knowledge and transferability of contextual representations. In *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long and Short Papers)*, pp. 1073–1094, Minneapolis, Minnesota, 2019a. Association for Computational Linguistics. doi: 10.18653/v1/N19-1112. URL https://aclanthology.org/N19-1112.

Yinhan Liu, Myle Ott, Naman Goyal, Jingfei Du, Mandar Joshi, Danqi Chen, Omer Levy, Mike Lewis, Luke Zettlemoyer, and Veselin Stoyanov. RoBERTa: A robustly optimized BERT pretraining approach. 2019b.

Patrick E McKnight and Julius Najab. *Mann-Whitney U Test*. John Wiley & Sons, Inc., Hoboken, NJ, USA, 2010.

George A. Miller. WordNet: A lexical database for English. In *Speech and Natural Language: Proceedings of a Workshop Held at Harriman, New York, February 23-26, 1992*, 1992. URL https://aclanthology.org/H92-1116.

Anna Rogers, Olga Kovaleva, and Anna Rumshisky. A primer in BERTology: What we know about how BERT works. *Transactions of the Association for Computational Linguistics*, 8:842–866, 2020. doi: 10.1162/tacl_a_00349. URL https://aclanthology.org/2020.tacl-1.54.

Victor Sanh, Lysandre Debut, Julien Chaumond, and Thomas Wolf. DistilBERT, a distilled version of BERT: smaller, faster, cheaper and lighter. 2019.

Ashish Vaswani, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N. Gomez, Lukasz Kaiser, and Illia Polosukhin. Attention is all you need. In Isabelle Guyon, Ulrike von Luxburg, Samy Bengio, Hanna M. Wallach, Rob Fergus, S. V. N. Vishwanathan, and Roman Garnett (eds.), *Advances in Neural Information Processing Systems 30: Annual Conference on Neural Information Processing Systems 2017, December 4-9, 2017, Long Beach, CA, USA*, pp. 5998–6008, 2017. URL https://proceedings.neurips.cc/paper/2017/hash/3f5ee243547dee91fbd053c1c4a845aa-Abstract.html.

Jesse Vig and Yonatan Belinkov. Analyzing the structure of attention in a transformer language model. In *Proceedings of the 2019 ACL Workshop BlackboxNLP: Analyzing and Interpreting Neural Networks for NLP*, pp. 63–76, Florence, Italy, 2019. Association for Computational Linguistics. doi: 10.18653/v1/W19-4808. URL https://aclanthology.org/W19-4808.

Sarah Wiegreffe and Yuval Pinter. Attention is not not explanation. In *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, pp. 11–20, Hong Kong, China, 2019. Association for Computational Linguistics. doi: 10.18653/v1/D19-1002. URL https://aclanthology.org/D19-1002.

Thomas Wolf, Lysandre Debut, Victor Sanh, Julien Chaumond, Clement Delangue, Anthony Moi, Pierric Cistac, Tim Rault, Remi Louf, Morgan Funtowicz, Joe Davison, Sam Shleifer, Patrick von Platen, Clara Ma, Yacine Jernite, Julien Plu, Canwen Xu, Teven Le Scao, Sylvain Gugger, Mariama Drame, Quentin Lhoest, and Alexander Rush. Transformers: State-of-the-art natural language processing. In *Proceedings of the 2020 Conference on Empirical Methods*

in Natural Language Processing: System Demonstrations, pp. 38–45, Online, 2020. Association for Computational Linguistics. doi: 10.18653/v1/2020.emnlp-demos.6. URL https://aclanthology.org/2020.emnlp-demos.6.

A Appendix

A.1 Implementation Details

We follow the standard best practices for our codebase, both for deep learning and for Python development in general. These are the core tools we relied on:

- *Transformers by HuggingFace* (Wolf et al., 2020), to get ready-to-use transformer-based LLMs;
- *Datasets by HuggingFace* (Lhoest et al., 2021), to handle the creation and processing of our dataset;
- *DVC* (Kuprieiev et al., 2023), for versioning our datasets and results accordingly;
- *NLTK* (Bird et al., 2009) for easy access to WordNet.

Table 2: The HuggingFace transformers used in Section 3, along with some of their specifics.

official name	Num. Layers	Num. Params
roberta-base	12	125M
bert-base-uncased	12	110M
roberta-large	24	355M
xlm-roberta-base	12	125M
distilbert-base-uncased	6	66M

A.2 Data

To produce the dataset we utilized WordNet. For each synset in it, we retrieved all the lemmas and all the examples. Then, we kept only the examples having an exact match with at least one of the lemmas for their synset. We tokenized the remaining sentences and discarded the ones shorter than 5 tokens. With this procedure, we ended up with a total of 20285 sentences with the length distribution shown in Figure 2.

This was done to ensure both high-quality sentences (WordNet is manually annotated) and that the target token for the perturbation is a ”meaningful” one and not a stopword (which could’ve added negative biases).

A.3 Full Results

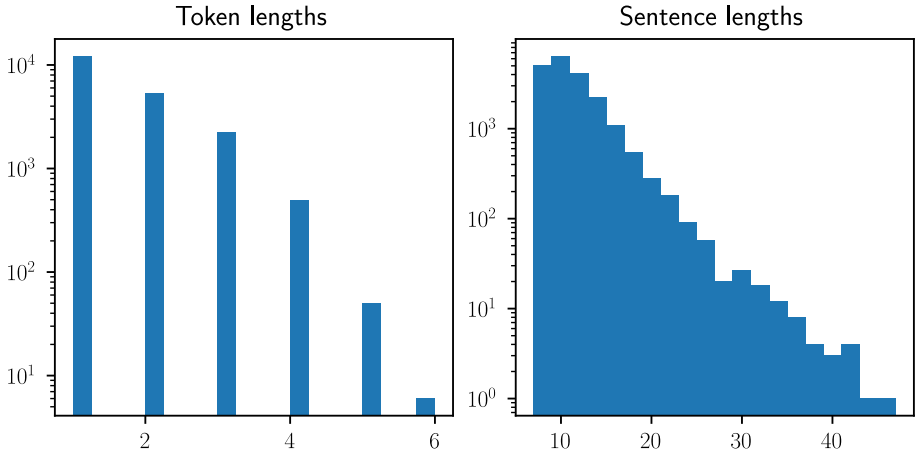

Figure 2: The distributions of the perturbed token lengths (*left*) and the sentence lengths (*right*). Both are calculated in number of wordpieces.

Table 3: The table shows, for the original dataset $\mathcal{S}$, the mean $\pm$ std of: attention $\mathbf{A}$, token attention $\mathbf{A_{ii}}$, sentence attention $\mathbf{A_{ij}}$, correlation ρ and likelihood L_s.

encoder	layer	$\bar{\mathbf{A}}$	$\bar{\mathbf{A_{ii}}}$	$\bar{\mathbf{A_{ij}}}$	$\bar{L_s}$	$\bar{\rho}$
BERT	0	0.099 ± 0.026	0.110 ± 0.028	0.098 ± 0.026	0.664 ± 0.356	-0.146
	1	0.099 ± 0.026	0.062 ± 0.018	0.100 ± 0.026	0.664 ± 0.356	0.008
	2	0.099 ± 0.026	0.078 ± 0.022	0.099 ± 0.026	0.664 ± 0.356	-0.035
	3	0.099 ± 0.026	0.047 ± 0.021	0.100 ± 0.026	0.664 ± 0.356	-0.220
	4	0.099 ± 0.026	0.056 ± 0.023	0.100 ± 0.026	0.664 ± 0.356	-0.236
	5	0.099 ± 0.026	0.034 ± 0.016	0.101 ± 0.026	0.664 ± 0.356	-0.291
	6	0.099 ± 0.026	0.040 ± 0.018	0.100 ± 0.026	0.664 ± 0.356	-0.222
	7	0.099 ± 0.026	0.038 ± 0.018	0.101 ± 0.026	0.664 ± 0.356	-0.314
	8	0.099 ± 0.026	0.038 ± 0.017	0.101 ± 0.026	0.664 ± 0.356	-0.150
	9	0.099 ± 0.026	0.075 ± 0.032	0.100 ± 0.026	0.664 ± 0.356	0.095
	10	0.099 ± 0.026	0.089 ± 0.049	0.100 ± 0.026	0.664 ± 0.356	0.163
	11	0.099 ± 0.026	0.070 ± 0.030	0.100 ± 0.026	0.664 ± 0.356	0.266
RoBERTa base	0	0.100 ± 0.025	0.158 ± 0.031	0.098 ± 0.025	0.938 ± 0.197	0.015
	1	0.100 ± 0.025	0.052 ± 0.029	0.101 ± 0.026	0.938 ± 0.197	0.027
	2	0.100 ± 0.025	0.057 ± 0.019	0.101 ± 0.026	0.938 ± 0.197	0.077
	3	0.100 ± 0.025	0.047 ± 0.015	0.101 ± 0.026	0.938 ± 0.197	0.064
	4	0.100 ± 0.025	0.052 ± 0.018	0.101 ± 0.025	0.938 ± 0.197	-0.190
	5	0.100 ± 0.025	0.048 ± 0.017	0.101 ± 0.025	0.938 ± 0.197	-0.014
	6	0.100 ± 0.025	0.052 ± 0.022	0.101 ± 0.025	0.938 ± 0.197	-0.125
	7	0.100 ± 0.025	0.062 ± 0.024	0.100 ± 0.026	0.938 ± 0.197	-0.072
	8	0.100 ± 0.025	0.045 ± 0.021	0.101 ± 0.026	0.938 ± 0.197	-0.246
	9	0.100 ± 0.025	0.054 ± 0.035	0.101 ± 0.026	0.938 ± 0.197	-0.275
	10	0.100 ± 0.025	0.066 ± 0.027	0.100 ± 0.025	0.938 ± 0.197	-0.245
	11	0.100 ± 0.025	0.124 ± 0.048	0.099 ± 0.025	0.938 ± 0.197	0.247
XLM-R	0	0.089 ± 0.024	0.123 ± 0.039	0.089 ± 0.024	0.943 ± 0.176	-0.088
	1	0.089 ± 0.024	0.071 ± 0.031	0.090 ± 0.025	0.943 ± 0.176	-0.076
	2	0.089 ± 0.024	0.058 ± 0.023	0.090 ± 0.025	0.943 ± 0.176	0.122
	3	0.089 ± 0.024	0.075 ± 0.020	0.090 ± 0.025	0.943 ± 0.176	0.130
	4	0.089 ± 0.024	0.061 ± 0.018	0.090 ± 0.025	0.943 ± 0.176	0.075
	5	0.089 ± 0.024	0.068 ± 0.014	0.090 ± 0.025	0.943 ± 0.176	-0.258
	6	0.089 ± 0.024	0.045 ± 0.017	0.091 ± 0.025	0.943 ± 0.176	0.002
	7	0.089 ± 0.024	0.054 ± 0.017	0.091 ± 0.025	0.943 ± 0.176	-0.548
	8	0.089 ± 0.024	0.055 ± 0.019	0.091 ± 0.025	0.943 ± 0.176	-0.407
	9	0.089 ± 0.024	0.083 ± 0.030	0.090 ± 0.024	0.943 ± 0.176	-0.441
	10	0.089 ± 0.024	0.082 ± 0.037	0.090 ± 0.024	0.943 ± 0.176	-0.543
	11	0.089 ± 0.024	0.132 ± 0.063	0.089 ± 0.024	0.943 ± 0.176	0.332
RoBERTa large	0	0.100 ± 0.025	0.199 ± 0.073	0.098 ± 0.024	0.947 ± 0.172	-0.166
	1	0.100 ± 0.025	0.047 ± 0.030	0.101 ± 0.026	0.947 ± 0.172	0.180
	2	0.100 ± 0.025	0.041 ± 0.024	0.101 ± 0.026	0.947 ± 0.172	0.043
	3	0.100 ± 0.025	0.046 ± 0.023	0.101 ± 0.026	0.947 ± 0.172	0.088
	4	0.100 ± 0.025	0.053 ± 0.019	0.101 ± 0.025	0.947 ± 0.172	-0.082
	5	0.100 ± 0.025	0.026 ± 0.015	0.102 ± 0.026	0.947 ± 0.172	0.008
	6	0.100 ± 0.025	0.029 ± 0.012	0.102 ± 0.026	0.947 ± 0.172	0.009
	7	0.100 ± 0.025	0.062 ± 0.020	0.101 ± 0.025	0.947 ± 0.172	-0.189
	8	0.100 ± 0.025	0.079 ± 0.025	0.101 ± 0.025	0.947 ± 0.172	-0.164
	9	0.100 ± 0.025	0.057 ± 0.018	0.101 ± 0.026	0.947 ± 0.172	-0.121
	10	0.100 ± 0.025	0.053 ± 0.017	0.101 ± 0.025	0.947 ± 0.172	-0.113
	11	0.100 ± 0.025	0.052 ± 0.020	0.101 ± 0.025	0.947 ± 0.172	-0.032
	12	0.100 ± 0.025	0.052 ± 0.017	0.101 ± 0.025	0.947 ± 0.172	-0.154
	13	0.100 ± 0.025	0.042 ± 0.021	0.101 ± 0.025	0.947 ± 0.172	-0.048
	14	0.100 ± 0.025	0.032 ± 0.018	0.102 ± 0.026	0.947 ± 0.172	-0.186
	15	0.100 ± 0.025	0.040 ± 0.019	0.101 ± 0.026	0.947 ± 0.172	-0.020
	16	0.100 ± 0.025	0.042 ± 0.018	0.101 ± 0.026	0.947 ± 0.172	-0.061
	17	0.100 ± 0.025	0.042 ± 0.019	0.101 ± 0.026	0.947 ± 0.172	-0.013
	18	0.100 ± 0.025	0.038 ± 0.019	0.102 ± 0.026	0.947 ± 0.172	-0.112
	19	0.100 ± 0.025	0.045 ± 0.013	0.101 ± 0.026	0.947 ± 0.172	-0.073
	20	0.100 ± 0.025	0.055 ± 0.019	0.101 ± 0.026	0.947 ± 0.172	-0.007
	21	0.100 ± 0.025	0.068 ± 0.034	0.100 ± 0.026	0.947 ± 0.172	-0.195
	22	0.100 ± 0.025	0.052 ± 0.030	0.101 ± 0.026	0.947 ± 0.172	-0.171
	23	0.100 ± 0.025	0.134 ± 0.040	0.099 ± 0.025	0.947 ± 0.172	0.183
DistilBERT	0	0.099 ± 0.026	0.096 ± 0.023	0.099 ± 0.026	0.785 ± 0.293	-0.202
	1	0.099 ± 0.026	0.091 ± 0.020	0.099 ± 0.026	0.785 ± 0.293	-0.111
	2	0.099 ± 0.026	0.045 ± 0.017	0.100 ± 0.026	0.785 ± 0.293	-0.163
	3	0.099 ± 0.026	0.039 ± 0.018	0.100 ± 0.026	0.785 ± 0.293	-0.185
	4	0.099 ± 0.026	0.065 ± 0.022	0.100 ± 0.026	0.785 ± 0.293	0.033
	5	0.099 ± 0.026	0.063 ± 0.024	0.100 ± 0.026	0.785 ± 0.293	0.017

Table 4: The table shows, for the perturbed dataset $\hat{\mathcal{S}}$, the mean $\pm$ std of: attention $\hat{\mathbf{A}}$, token attention $\hat{\mathbf{A}}_{\mathbf{ii}}$, sentence attention $\hat{\mathbf{A}}_{\mathbf{ij}}$, correlation $\hat{\rho}$ and likelihood $\hat{L}_s$.

encoder	layer	$\bar{\mathbf{A}}$	$\bar{\mathbf{A}}_{\mathbf{ii}}$	$\bar{\mathbf{A}}_{\mathbf{ij}}$	$\bar{L}_s$	$\bar{\rho}$
BERT	0	0.099 ± 0.026	0.099 ± 0.027	0.099 ± 0.026	0.096 ± 0.198	0.143
	1	0.099 ± 0.026	0.050 ± 0.017	0.100 ± 0.026	0.096 ± 0.198	0.142
	2	0.099 ± 0.026	0.081 ± 0.023	0.099 ± 0.026	0.096 ± 0.198	0.447
	3	0.099 ± 0.026	0.049 ± 0.022	0.100 ± 0.026	0.096 ± 0.198	0.345
	4	0.099 ± 0.026	0.065 ± 0.021	0.100 ± 0.026	0.096 ± 0.198	0.084
	5	0.099 ± 0.026	0.051 ± 0.023	0.100 ± 0.026	0.096 ± 0.198	0.065
	6	0.099 ± 0.026	0.049 ± 0.023	0.100 ± 0.026	0.096 ± 0.198	0.353
	7	0.099 ± 0.026	0.060 ± 0.035	0.100 ± 0.026	0.096 ± 0.198	0.264
	8	0.099 ± 0.026	0.047 ± 0.021	0.100 ± 0.026	0.096 ± 0.198	0.262
	9	0.099 ± 0.026	0.063 ± 0.041	0.100 ± 0.026	0.096 ± 0.198	0.643
	10	0.099 ± 0.026	0.062 ± 0.052	0.100 ± 0.026	0.096 ± 0.198	0.588
	11	0.099 ± 0.026	0.045 ± 0.035	0.100 ± 0.026	0.096 ± 0.198	0.576
RoBERTa base	0	0.100 ± 0.025	0.166 ± 0.039	0.098 ± 0.025	0.072 ± 0.174	-0.157
	1	0.100 ± 0.025	0.050 ± 0.023	0.101 ± 0.026	0.072 ± 0.174	0.417
	2	0.100 ± 0.025	0.050 ± 0.018	0.101 ± 0.026	0.072 ± 0.174	0.440
	3	0.100 ± 0.025	0.038 ± 0.018	0.101 ± 0.026	0.072 ± 0.174	0.488
	4	0.100 ± 0.025	0.049 ± 0.021	0.101 ± 0.026	0.072 ± 0.174	0.521
	5	0.100 ± 0.025	0.038 ± 0.015	0.101 ± 0.026	0.072 ± 0.174	0.337
	6	0.100 ± 0.025	0.064 ± 0.019	0.101 ± 0.025	0.072 ± 0.174	-0.038
	7	0.100 ± 0.025	0.062 ± 0.028	0.100 ± 0.026	0.072 ± 0.174	0.544
	8	0.100 ± 0.025	0.057 ± 0.035	0.100 ± 0.026	0.072 ± 0.174	0.541
	9	0.100 ± 0.025	0.073 ± 0.051	0.100 ± 0.026	0.072 ± 0.174	0.609
	10	0.100 ± 0.025	0.071 ± 0.048	0.100 ± 0.026	0.072 ± 0.174	0.739
	11	0.100 ± 0.025	0.043 ± 0.033	0.101 ± 0.026	0.072 ± 0.174	0.802
XLM-R	0	0.089 ± 0.024	0.151 ± 0.053	0.088 ± 0.024	0.017 ± 0.071	-0.429
	1	0.089 ± 0.024	0.116 ± 0.031	0.088 ± 0.024	0.017 ± 0.071	0.125
	2	0.089 ± 0.024	0.065 ± 0.022	0.090 ± 0.025	0.017 ± 0.071	0.283
	3	0.089 ± 0.024	0.059 ± 0.020	0.090 ± 0.025	0.017 ± 0.071	0.425
	4	0.089 ± 0.024	0.058 ± 0.022	0.090 ± 0.025	0.017 ± 0.071	0.565
	5	0.089 ± 0.024	0.058 ± 0.017	0.090 ± 0.025	0.017 ± 0.071	0.610
	6	0.089 ± 0.024	0.051 ± 0.021	0.091 ± 0.025	0.017 ± 0.071	0.516
	7	0.089 ± 0.024	0.055 ± 0.023	0.090 ± 0.025	0.017 ± 0.071	0.713
	8	0.089 ± 0.024	0.057 ± 0.026	0.090 ± 0.025	0.017 ± 0.071	0.622
	9	0.089 ± 0.024	0.095 ± 0.042	0.089 ± 0.025	0.017 ± 0.071	0.638
	10	0.089 ± 0.024	0.083 ± 0.050	0.089 ± 0.025	0.017 ± 0.071	0.709
	11	0.089 ± 0.024	0.051 ± 0.034	0.090 ± 0.025	0.017 ± 0.071	0.767
RoBERTa large	0	0.100 ± 0.025	0.219 ± 0.075	0.097 ± 0.024	0.055 ± 0.149	-0.410
	1	0.100 ± 0.025	0.034 ± 0.020	0.101 ± 0.026	0.055 ± 0.149	0.439
	2	0.100 ± 0.025	0.036 ± 0.020	0.101 ± 0.026	0.055 ± 0.149	0.268
	3	0.100 ± 0.025	0.041 ± 0.018	0.101 ± 0.026	0.055 ± 0.149	0.441
	4	0.100 ± 0.025	0.048 ± 0.019	0.101 ± 0.026	0.055 ± 0.149	0.195
	5	0.100 ± 0.025	0.021 ± 0.013	0.102 ± 0.026	0.055 ± 0.149	0.209
	6	0.100 ± 0.025	0.031 ± 0.014	0.101 ± 0.026	0.055 ± 0.149	0.387
	7	0.100 ± 0.025	0.058 ± 0.022	0.101 ± 0.025	0.055 ± 0.149	0.214
	8	0.100 ± 0.025	0.074 ± 0.026	0.100 ± 0.025	0.055 ± 0.149	0.018
	9	0.100 ± 0.025	0.050 ± 0.018	0.101 ± 0.026	0.055 ± 0.149	0.271
	10	0.100 ± 0.025	0.048 ± 0.015	0.101 ± 0.026	0.055 ± 0.149	0.432
	11	0.100 ± 0.025	0.040 ± 0.017	0.101 ± 0.026	0.055 ± 0.149	0.156
	12	0.100 ± 0.025	0.052 ± 0.016	0.101 ± 0.026	0.055 ± 0.149	0.470
	13	0.100 ± 0.025	0.031 ± 0.014	0.102 ± 0.026	0.055 ± 0.149	0.093
	14	0.100 ± 0.025	0.030 ± 0.012	0.102 ± 0.026	0.055 ± 0.149	0.189
	15	0.100 ± 0.025	0.030 ± 0.012	0.102 ± 0.026	0.055 ± 0.149	0.407
	16	0.100 ± 0.025	0.037 ± 0.013	0.101 ± 0.026	0.055 ± 0.149	0.244
	17	0.100 ± 0.025	0.041 ± 0.014	0.101 ± 0.026	0.055 ± 0.149	0.299
	18	0.100 ± 0.025	0.042 ± 0.017	0.101 ± 0.026	0.055 ± 0.149	0.088
	19	0.100 ± 0.025	0.053 ± 0.020	0.101 ± 0.026	0.055 ± 0.149	0.534
	20	0.100 ± 0.025	0.057 ± 0.036	0.100 ± 0.026	0.055 ± 0.149	0.528
	21	0.100 ± 0.025	0.071 ± 0.055	0.100 ± 0.026	0.055 ± 0.149	0.648
	22	0.100 ± 0.025	0.056 ± 0.041	0.100 ± 0.026	0.055 ± 0.149	0.681
	23	0.100 ± 0.025	0.046 ± 0.035	0.101 ± 0.026	0.055 ± 0.149	0.823
DistilBERT	0	0.099 ± 0.026	0.086 ± 0.020	0.099 ± 0.026	0.017 ± 0.069	-0.133
	1	0.099 ± 0.026	0.079 ± 0.019	0.099 ± 0.026	0.017 ± 0.069	0.489
	2	0.099 ± 0.026	0.046 ± 0.033	0.100 ± 0.026	0.017 ± 0.069	0.567
	3	0.099 ± 0.026	0.044 ± 0.047	0.100 ± 0.027	0.017 ± 0.069	0.594
	4	0.099 ± 0.026	0.045 ± 0.035	0.100 ± 0.026	0.017 ± 0.069	0.688
	5	0.099 ± 0.026	0.035 ± 0.033	0.101 ± 0.026	0.017 ± 0.069	0.558