no graph layer, GRMM-1 for the model with a single graph layer, and so forth for the others. From the figure, we find that:

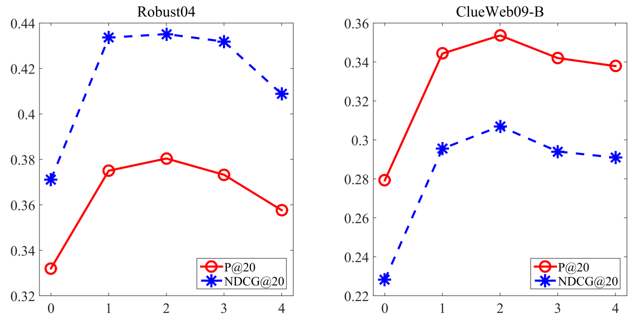

Figure 4: Influence of different graph layer numbers.

- GRMM-1 dramatically boosts the performance against GRMM-0. This observation is consistent with Section 4.3 that propagating the information within the graph helps to understand both query-term interaction and document-level word relationships. The exact/similar query-document matching signals are likely to be strengthened or weakened according to intra-document word relationships.
- GRMM-2 improves, not as much though, GRMM-1 by incorporating second-order neighbours. It suggests that the information from 2-hops away also contributes to the term relations. The nodes serving as a bridge can exchange the message from two ends in this way.
- However, when further stacking more layers, GRMM-3 and GRMM-4 suffer from slight performance degradation. The reason could be nodes receive more noises from high-order neighbours which burdens the training of parameters. Too much propagation may also lead to the issue of over-smooth (**?**). A two-layer propagation seems to be sufficient for capturing useful word relationships.
- Overall, there is a tremendous gap between using and not using the contextual information, and the model peaks at layer $t = 2$ on both datasets. The tendency supports our hypothesis that it is essential to consider term-level interaction and document-level word relationships jointly for ad-hoc retrieval.

4.5 Study of Graph Readout (RQ3)

We also explored the effect of graph readout for each query term. Figure 5 summarises the experimental performance w.r.t different k values of k-max-pooling. From the figure, we find that:

- The performance steadily grows from $k = 10$ to $k = 40$, which implies that a small feature dimension may limit the representation of terms. By enlarging the k value, the relevant term with more matching signals can distinguish from the irrelevant one with less.

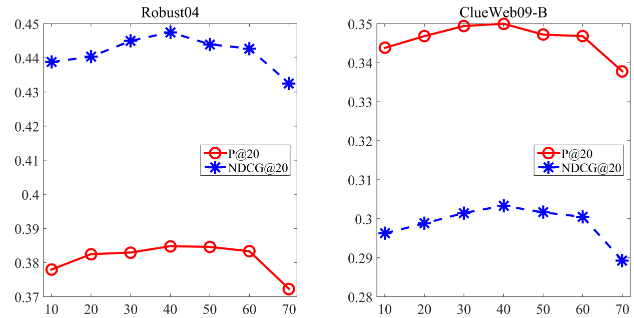

Figure 5: Influence of different k values of k-max pooling.

- The trend, however, declines until $k = 70$, which implies that a large feature dimension may bring negative influence. It can be explained that a large k value may have a bias to the document length, where longer documents tend to have more matching signals.
- Overall, there are no apparent sharp rises and falls in the figure, which tells that GRMM is not that sensitive to the selection of k value. Notably, almost all performances (except $k = 70$) exceed the baselines in Table 2, suggesting that determinative matching signals are acquired during the graph-based interactions before feeding into the readout layer.

5 Conclusion

In this paper, we introduced a new ad-hoc retrieval approach GRMM which explicitly incorporates document-level word relationships into the matching function. The flexible graph structure allows the model to find more comprehensive matching patterns and less noises. GRMM exceedingly advances the performance over various baselines, where it empirically witnesses an increment by a large margin on longer documents. Further studies exhibited the rationality and effectiveness of GRMM. There are also possible extensions, such as training with large click logs (**?**) and query descriptions. Another interesting future work is to extend the current graph with lexical or knowledge graphs which might contain more useful information.

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