

Parameters Learned in the Comparison of Retrieval Models using Term Dependencies

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1 Introduction

This technical report details the comparison of term dependency retrieval models. The intention is to provide sufficient details to facilitate the recreation of all results reported by Huston and Croft [3].

The structure of this document is as follows. First, we define the set of query folds using topic ids. Second, we define each of the retrieval models, and report the learned parameters for each fold and collection. Third, we detail the observed retrieval performance of each query fold. Finally, we report all p -values computed for pair-wise comparisons of each retrieval models to a specified baseline model.

2 Query Folds

For each collection, all available TREC topics were pooled, then randomly divided into 5 folds.

Collection	Query Set	Table
Robust-04	Titles	Table 1
Robust-04	descriptions	Table 2
GOV2	Titles	Table 3
GOV2	descriptions	Table 4
ClueWeb-09-Cat-B	Titles	Table 5
ClueWeb-09-Cat-B	descriptions	Table 6

Table 1: Query folds for Robust-04 topic Titles, each cell is a TREC topic id.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
1	302	301	306	320	304
2	303	308	307	325	305
3	309	312	313	330	310
4	316	322	321	332	311
5	317	327	324	335	314
6	319	328	326	337	315
7	323	338	334	342	318
8	331	343	347	344	329
9	336	348	351	350	333
10	341	349	354	355	339
11	356	352	358	368	340
12	357	360	361	377	345
13	370	364	362	379	346
14	373	365	363	387	353
15	378	369	376	393	359
16	381	371	380	398	366
17	383	374	382	402	367
18	392	386	396	405	372
19	394	390	404	407	375
20	406	397	413	408	384
21	410	403	415	412	385
22	411	419	417	420	388
23	414	422	427	421	389
24	426	423	436	425	391
25	428	424	437	430	395
26	433	432	439	431	399
27	447	434	444	435	400
28	448	440	445	438	401
29	601	446	449	616	409
30	607	602	450	618	416
31	608	604	603	625	418
32	612	611	605	630	429
33	617	623	606	633	441
34	619	624	614	636	442
35	635	627	620	639	443
36	641	632	622	649	609
37	642	638	626	650	610
38	646	643	628	653	613
39	647	651	631	655	615
40	654	652	637	657	621
41	656	663	644	659	629
42	662	674	648	667	634
43	665	675	661	668	640
44	669	678	664	672	645
45	670	680	666	673	658
46	679	683	671	676	660
47	684	688	677	682	681
48	690	689	685	686	694
49	692	695	687	691	696
50	700	698	693	697	699

Table 2: Query folds for Robust-04 topic descriptions, each cell is a TREC topic id.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
1	309	301	302	308	307
2	312	303	305	313	311
3	315	304	306	314	319
4	317	324	310	325	322
5	320	329	316	327	334
6	326	335	318	331	336
7	328	337	321	341	348
8	330	343	323	344	352
9	332	349	333	345	356
10	340	353	338	350	357
11	342	359	339	351	362
12	346	361	358	355	363
13	347	373	371	360	374
14	354	379	375	364	376
15	365	380	383	367	384
16	366	381	387	368	390
17	370	382	388	369	394
18	372	385	392	386	408
19	377	389	414	395	410
20	378	396	415	397	412
21	391	401	419	398	422
22	393	407	420	402	425
23	399	416	431	404	430
24	400	428	435	409	440
25	403	429	437	411	442
26	405	433	439	413	443
27	406	436	441	417	444
28	423	446	601	418	602
29	426	449	603	421	619
30	427	607	605	424	620
31	432	608	606	450	622
32	434	612	611	609	624
33	438	614	617	613	633
34	445	616	627	621	636
35	447	623	635	626	641
36	448	625	637	631	643
37	604	628	644	632	653
38	610	629	648	639	655
39	615	630	652	640	656
40	618	646	660	642	657
41	634	649	664	647	658
42	638	651	665	661	659
43	645	654	666	662	670
44	650	663	669	667	672
45	671	679	675	668	673
46	674	682	676	683	678
47	677	691	688	687	680
48	681	695	690	689	684
49	686	696	692	693	685
50	697	698	694	700	699

Table 3: Query folds for GOV2 topic Titles, each cell is a TREC topic id.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
1	712	704	702	701	711
2	722	708	703	713	716
3	731	709	705	714	719
4	740	715	706	717	739
5	749	718	707	723	741
6	750	738	710	726	742
7	751	743	720	727	744
8	759	755	721	729	745
9	764	756	724	732	746
10	765	761	725	735	748
11	774	762	728	760	752
12	775	763	730	769	753
13	782	772	733	778	754
14	784	779	734	780	758
15	785	792	736	787	766
16	786	802	737	790	767
17	788	806	747	791	768
18	789	808	757	793	776
19	794	809	770	795	777
20	798	814	771	799	781
21	801	816	773	811	783
22	805	818	797	813	796
23	823	821	803	819	800
24	824	822	804	826	807
25	825	831	810	827	815
26	832	836	812	837	817
27	833	839	820	842	829
28	835	840	828	846	830
29	845	843	834	848	838
30	850	847	844	849	841

Table 4: Query folds for GOV2 topic descriptions, each cell is a TREC topic id.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
1	701	710	707	705	702
2	703	716	715	706	708
3	704	720	718	711	709
4	713	730	723	712	714
5	733	735	727	717	721
6	734	742	728	719	725
7	738	745	729	722	731
8	739	752	740	724	743
9	744	758	741	726	747
10	750	759	746	732	748
11	753	761	751	736	749
12	757	764	779	737	754
13	763	776	782	755	760
14	768	777	784	756	762
15	770	781	786	765	766
16	772	791	788	771	767

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Table 4 – *Continued from previous page*

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
17	773	801	789	787	769
18	775	806	794	790	774
19	778	810	795	796	792
20	780	812	803	797	798
21	783	821	805	802	799
22	785	822	813	807	800
23	793	829	819	809	811
24	804	837	823	820	814
25	808	839	827	824	816
26	815	841	830	828	826
27	817	842	832	835	831
28	818	843	834	840	836
29	825	844	845	846	838
30	833	847	849	848	850

Table 5: Query folds for ClueWeb-09-Cat-B title topics, each cell is a TREC query id.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
1	1	2	3	5	4
2	6	7	15	10	13
3	8	9	17	11	16
4	25	14	18	12	24
5	27	20	19	28	29
6	35	21	22	31	39
7	36	23	30	42	48
8	41	26	32	50	52
9	53	33	38	59	64
10	54	34	43	63	65
11	55	37	46	66	72
12	57	40	47	69	90
13	58	44	49	74	91
14	60	45	61	78	96
15	62	51	70	79	97
16	73	56	76	84	98
17	75	67	80	95	104
18	92	68	81	101	106
19	93	71	82	108	107
20	94	77	85	118	112
21	100	83	86	122	114
22	102	89	87	124	119
23	105	99	88	129	121
24	117	110	103	132	123
25	120	111	109	135	126
26	125	115	113	145	127
27	128	116	131	147	134
28	130	138	136	148	140
29	133	142	137	149	143
30	141	144	139	150	146

Table 6: Query folds for GOV2 description topics, each cell is a TREC query id.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5
1	12	2	9	3	1
2	14	4	15	13	6
3	16	5	29	24	7
4	18	10	36	33	8
5	19	11	39	35	17
6	26	21	43	40	20
7	27	22	48	46	25
8	28	23	55	50	38
9	30	34	59	52	41
10	31	37	68	56	42
11	32	53	69	58	44
12	47	60	70	63	45
13	51	61	73	75	49
14	54	62	88	79	74
15	57	67	90	81	80
16	64	72	91	86	83
17	65	76	96	92	89
18	66	78	100	101	93
19	71	82	102	109	95
20	77	84	103	110	97
21	87	85	106	111	99
22	94	98	108	116	105
23	107	104	112	121	113
24	118	124	114	130	115
25	122	138	119	131	117
26	125	140	120	133	123
27	132	141	135	139	126
28	134	144	136	142	127
29	137	145	146	143	128
30	147	150	149	148	129

3 Learned Parameter Settings

In this section, we provide a specific definition of all compared retrieval models. We also detail the learned settings for the parameters for each retrieval model, for each fold, collection, and query set. We present retrieval models in the following order:

1. query likelihood (QL);
2. the sequential dependence model (SDM);
3. SDM variant: Uni+O234;
4. SDM variant: Uni+O234+U2;
5. SDM variant: Uni+O23+U23;
6. SDM variant: Uni+O234+U234;
7. the weighted sequential dependence model (WSDM);
8. WSDM variant: WSDM-Int;
9. WSDM variant: WSDM-Int-3;
10. PLM;
11. PLM-2;
12. PL2;
13. pDFR-BiL2;
14. pDFR-PL2;
15. BM25;
16. BM25-TP;
17. BM25-TP2; and
18. BM25-Span.

3.1 Query Likelihood

The ranking function for the Dirichlet smoothed, Query Likelihood model [10] is defined as:

$$P(D_j|Q) \stackrel{rank}{=} \sum_{q_i \in Q} \frac{tf_{q_i, D_j} + \mu \cdot \frac{cf_{q_i}}{|C|}}{|D_j| + \mu}$$

where μ is the smoothing parameter. The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	μ	935	852	844	878	1161	934	885
Rob-04	Desc.	μ	2103	2397	2108	2102	2118	2166	2107
GOV2	Titles	μ	1446	1462	1525	1474	1496	1481	1477
GOV2	Desc.	μ	2087	1973	2288	2091	2094	2107	2121
Clue-B	Titles	μ	2300	2141	3130	2637	2528	2547	2531
Clue-B	Desc.	μ	1925	2128	2026	2070	2011	2032	2084

3.2 Sequential Dependence Model

The ranking function for the sequential dependence model (SDM) [5] is defined as:

$$\begin{aligned}
 P(D|Q) &\stackrel{\text{rank}}{=} \sum_{c \in C(Q)} \lambda_C f_C(c) \\
 &= \sum_{c \in T} \lambda_T f_T(c) + \sum_{c \in O} \lambda_O f_O(c) + \sum_{c \in U} \lambda_U f_U(c) \\
 T &= \{q_i \in Q\} \\
 O = U &= \{(q_i, q_{i+1}) \in Q\} \\
 f_T(c) &= \log P(q_i|D) \\
 f_O(c) &= \log P(\#od1(q_i, q_{i+1})|D) \\
 f_U(c) &= \log P(\#uw8(q_i, q_{i+1})|D) \\
 P(x|D) &= \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu}
 \end{aligned}$$

where μ is the Dirichlet smoothing parameter, and the combination of features is controlled by three parameters, λ_T , λ_O and λ_U . $\#od1$ is the ordered window operator that matches adjacent terms in documents, $\#uw8$ is a unordered window operator that matches pairs of terms that occur within a window of 8 terms in documents. The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	μ	957	977	1893	999	1520	1270	1136
Rob-04	Titles	λ_T	0.884	0.883	0.856	0.869	0.871	0.873	0.86
Rob-04	Titles	λ_O	0.0674	0.0852	0.0844	0.089	0.0693	0.0791	0.0786
Rob-04	Titles	λ_U	0.049	0.0321	0.0591	0.0418	0.0594	0.0483	0.0612
Rob-04	Desc.	μ	2711	3575	2749	3465	2801	3060	3050
Rob-04	Desc.	λ_T	0.813	0.82	0.838	0.816	0.815	0.82	0.829
Rob-04	Desc.	λ_O	0.134	0.102	0.086	0.103	0.129	0.111	0.105
Rob-04	Desc.	λ_U	0.0533	0.0782	0.0762	0.0811	0.056	0.069	0.0657
GOV2	Titles	μ	2052	2076	1870	1876	1865	1948	1937
GOV2	Titles	λ_T	0.869	0.853	0.86	0.859	0.873	0.863	0.861
GOV2	Titles	λ_O	0.0433	0.0644	0.0498	0.0507	0.0502	0.0517	0.0513
GOV2	Titles	λ_U	0.0876	0.0824	0.09	0.0903	0.0766	0.0854	0.0881
GOV2	Desc.	μ	3283	3214	2966	3003	3601	3213	3070
GOV2	Desc.	λ_T	0.856	0.858	0.841	0.839	0.841	0.847	0.837
GOV2	Desc.	λ_O	0.0961	0.0791	0.101	0.102	0.114	0.0986	0.102
GOV2	Desc.	λ_U	0.0481	0.0631	0.0573	0.0588	0.0447	0.0544	0.0604
Clue-B	Titles	μ	3840	2698	6391	4328	4300	4311	4318
Clue-B	Titles	λ_T	0.875	0.883	0.737	0.859	0.874	0.846	0.859
Clue-B	Titles	λ_O	0.0575	0.0461	0.051	0.0561	0.0546	0.0531	0.056
Clue-B	Titles	λ_U	0.0672	0.0704	0.212	0.0852	0.0709	0.101	0.0852
Clue-B	Desc.	μ	2408	2683	3455	2580	2345	2694	2578
Clue-B	Desc.	λ_T	0.864	0.902	0.873	0.886	0.884	0.882	0.883
Clue-B	Desc.	λ_O	0.0359	0.00846	0.0355	0.0172	0.0156	0.0225	0.0117
Clue-B	Desc.	λ_U	0.0997	0.0893	0.0911	0.0964	0.101	0.0954	0.105

3.3 Sequential Dependence Model Variant: Uni+O234

The ranking function for the Uni+O234 variant of the sequential dependence model [5] is defined as:

$$\begin{aligned}
 P(D|Q) &\stackrel{\text{rank}}{=} \sum_{c \in C(Q)} \lambda_C f_C(c) \\
 &= \sum_{c \in T} \lambda_T f_T(c) + \sum_{c \in O} \lambda_{O2} f_{O2}(c) + \sum_{c \in O3} \lambda_{O3} f_{O3}(c) + \sum_{c \in O4} \lambda_{O4} f_{O4}(c) \\
 T &= \{q_i \in Q\} \\
 O2 &= \{(q_i, q_{i+1}) \in Q\} \\
 O3 &= \{(q_i, q_{i+1}, q_{i+2}) \in Q\} \\
 O4 &= \{(q_i, q_{i+1}, q_{i+2}, q_{i+3}) \in Q\} \\
 f_T(c) &= \log P(q_i|D) \\
 f_{O2}(c) &= \log P(\#od1(q_i, q_{i+1})|D) \\
 f_{O3}(c) &= \log P(\#od1(q_i, q_{i+1}, q_{i+2})|D) \\
 f_{O4}(c) &= \log P(\#od1(q_i, q_{i+1}, q_{i+2}, q_{i+3})|D) \\
 P(x|D) &= \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu}
 \end{aligned}$$

where μ is the smoothing parameter, and the combination of features is controlled by four parameters, λ_T , λ_{O2} , λ_{O3} and λ_{O4} . $\#od1$ is the ordered window operator that matches adjacent terms in documents. The learned settings for these parameters for each collection and query set fold are listed in the following table.

Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Robust-04								
Titles	μ	918	885	1292	1325	1500	1184	1074
Titles	λ_T	1.029	0.869	0.894	0.827	0.971	0.918	0.911
Titles	λ_{O2}	0.107	0.097	0.121	0.113	0.129	0.113	0.116
Titles	λ_{O3}	0.045	0.039	-0.011	0.05	0.078	0.04	0.014
Titles	λ_{O4}	-0.18	-0.0057	-0.0027	0.0099	-0.18	-0.072	-0.042
Desc.	μ	2999	3252	2790	3503	3627	3234	3624
Desc.	λ_T	0.786	0.734	0.837	0.817	0.8	0.795	0.774
Desc.	λ_{O2}	0.131	0.125	0.143	0.13	0.129	0.132	0.13
Desc.	λ_{O3}	0.083	0.059	0.0	0.047	0.07	0.052	0.083
Desc.	λ_{O4}	0.0	0.083	0.02	0.005	0.0017	0.022	0.013
GOV2								
Titles	μ	1816	2215	1952	1571	1789	1868	1799
Titles	λ_T	0.93	0.877	0.903	0.899	0.932	0.908	0.908
Titles	λ_{O2}	0.071	0.088	0.084	0.055	0.072	0.074	0.068
Titles	λ_{O3}	0.0	0.014	0.003	0.0093	-0.01	0.0031	0.0
Titles	λ_{O4}	-0.00095	0.021	0.0098	0.036	0.0058	0.014	0.023
Desc.	μ	3234	2837	3793	3337	3277	3296	3286
Desc.	λ_T	0.88	0.893	0.847	0.873	0.878	0.874	0.877
Desc.	λ_{O2}	0.104	0.108	0.098	0.1	0.117	0.106	0.105
Desc.	λ_{O3}	0.016	0.014	0.045	0.029	0.014	0.024	0.023
Desc.	λ_{O4}	0.0	-0.016	0.01	-0.0018	-0.0099	-0.0035	-0.0051

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Query Set	Param.	1	2	3	4	5	Avg.	Oracle
ClueWeb-09-Cat-B								
Titles	μ	2896	3363	5142	3597	3123	3624	3624
Titles	λ_T	0.936	0.885	0.908	0.918	0.918	0.913	0.912
Titles	λ_{O2}	0.059	0.051	0.069	0.06	0.058	0.059	0.059
Titles	λ_{O3}	0.023	0.05	0.023	0.033	0.014	0.028	0.028
Titles	λ_{O4}	-0.017	0.015	0.0	-0.011	0.0099	-0.00064	0.0
Desc.	μ	1888	1900	2474	1868	1927	2012	1883
Desc.	λ_T	0.927	0.925	0.923	0.932	0.942	0.93	0.95
Desc.	λ_{O2}	0.064	0.039	0.066	0.064	0.036	0.054	0.045
Desc.	λ_{O3}	0.0027	0.026	0.018	0.0032	0.022	0.014	0.022
Desc.	λ_{O4}	0.0063	0.0099	-0.0065	0.0	0.0	0.0019	-0.017

3.4 Sequential Dependence Model Variant: Uni+O234+U2

The ranking function for the Uni+O234+U2 variant of the sequential dependence model [5] is defined as:

$$\begin{aligned}
 P(D|Q) &\stackrel{\text{rank}}{=} \sum_{c \in C(Q)} \lambda_C f_C(c) \\
 &= \sum_{c \in T} \lambda_T f_T(c) + \sum_{c \in O} \lambda_{O2} f_{O2}(c) + \sum_{c \in O3} \lambda_{O3} f_{O3}(c) \\
 &\quad + \sum_{c \in O4} \lambda_{O4} f_{O4}(c) + \sum_{c \in U2} \lambda_{U2} f_{U2}(c)
 \end{aligned}$$

$$T = \{q_i \in Q\}$$

$$O2 = U2 = \{(q_i, q_{i+1}) \in Q\}$$

$$O3 = \{(q_i, q_{i+1}, q_{i+2}) \in Q\}$$

$$O4 = \{(q_i, q_{i+1}, q_{i+2}, q_{i+3}) \in Q\}$$

$$f_T(c) = \log P(q_i|D)$$

$$f_{O2}(c) = \log P(\#od1(q_i, q_{i+1})|D)$$

$$f_{O3}(c) = \log P(\#od1(q_i, q_{i+1}, q_{i+2})|D)$$

$$f_{O4}(c) = \log P(\#od1(q_i, q_{i+1}, q_{i+2}, q_{i+3})|D)$$

$$f_{U2}(c) = \log P(\#uw8(q_i, q_{i+1})|D)$$

$$P(x|D) = \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu}$$

where μ is the smoothing parameter, and the combination of features is controlled by five parameters, λ_T , λ_{O2} , λ_{O3} , λ_{O4} , and λ_{U2} . $\#od1$ is the ordered window operator that matches adjacent terms in documents, and $\#uw8$ is a unordered window operator that matches pairs of terms that occur within a window of 8 terms in documents. The learned settings for these parameters for each collection and query set fold are listed in the following table.

Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Robust-04								

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Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Titles	μ	1381	1366	1580	1070	1643	1408	1326
Titles	λ_T	0.846	0.815	0.842	0.814	0.808	0.825	0.823
Titles	λ_{O2}	0.046	0.06	0.067	0.088	0.061	0.065	0.06
Titles	λ_{O3}	0.016	0.053	0.0049	0.057	0.071	0.04	0.061
Titles	λ_{O4}	0.02	0.018	0.029	-0.0043	0.0099	0.014	0.0027
Titles	λ_{U2}	0.071	0.053	0.057	0.045	0.05	0.055	0.054
Desc.	μ	2957	4060	2894	2996	3704	3322	3466
Desc.	λ_T	0.782	0.722	0.772	0.811	0.731	0.763	0.727
Desc.	λ_{O2}	0.1	0.081	0.088	0.109	0.093	0.094	0.092
Desc.	λ_{O3}	0.128	0.0	0.054	0.035	0.12	0.067	0.05
Desc.	λ_{O4}	-0.065	0.145	0.018	0.0	0.0036	0.02	0.075
Desc.	λ_{U2}	0.056	0.052	0.068	0.046	0.052	0.055	0.056
GOV2								
Titles	μ	1920	2452	1889	1833	1922	2003	2013
Titles	λ_T	0.859	0.838	0.857	0.848	0.875	0.856	0.857
Titles	λ_{O2}	0.049	0.068	0.055	0.046	0.055	0.055	0.054
Titles	λ_{O3}	0.0097	0.004	0.014	0.011	-0.007	0.0064	0.0063
Titles	λ_{O4}	-0.005	0.0092	-0.0098	0.0097	0.0015	0.0011	0.0011
Titles	λ_{U2}	0.088	0.081	0.083	0.085	0.075	0.082	0.081
Desc.	μ	3671	3293	3442	3386	3933	3545	3466
Desc.	λ_T	0.832	0.848	0.826	0.846	0.825	0.835	0.836
Desc.	λ_{O2}	0.084	0.073	0.09	0.082	0.085	0.083	0.087
Desc.	λ_{O3}	0.018	0.033	0.018	0.029	0.037	0.027	0.017
Desc.	λ_{O4}	0.018	-0.019	0.013	-0.023	0.0016	-0.0019	0.0053
Desc.	λ_{U2}	0.048	0.065	0.053	0.066	0.051	0.057	0.054
ClueWeb-09-Cat-B								
Titles	μ	5502	3803	5350	6267	4785	5141	3662
Titles	λ_T	0.844	0.853	0.73	0.851	0.866	0.829	0.889
Titles	λ_{O2}	0.059	0.038	0.046	0.043	0.036	0.044	0.033
Titles	λ_{O3}	0.029	0.049	0.024	0.031	0.03	0.032	0.025
Titles	λ_{O4}	-0.0061	0.0098	-0.003	0.0	0.0018	0.0005	0.0
Titles	λ_{U2}	0.075	0.05	0.204	0.076	0.066	0.094	0.054
Desc.	μ	2349	2756	2966	2033	2736	2568	2636
Desc.	λ_T	0.891	0.872	0.862	0.871	0.866	0.872	0.859
Desc.	λ_{O2}	0.009	0.024	0.036	0.056	0.032	0.031	0.037
Desc.	λ_{O3}	0.02	-0.01	-0.014	-0.014	-0.01	-0.0056	-0.012
Desc.	λ_{O4}	0.0049	0.012	0.016	0.0039	0.0076	0.0087	0.019
Desc.	λ_{U2}	0.076	0.102	0.101	0.084	0.104	0.093	0.097

3.5 Sequential Dependence Model Variant: Uni+O23+U23

The ranking function for the Uni+O23+U23 variant of the sequential dependence model [5] is defined as:

$$\begin{aligned}
 P(D|Q) &\stackrel{\text{rank}}{=} \sum_{c \in C(Q)} \lambda_C f_C(c) \\
 &= \sum_{c \in T} \lambda_T f_T(c) + \sum_{c \in O} \lambda_{O2} f_{O2}(c) + \sum_{c \in O3} \lambda_{O3} f_{O3}(c) \\
 &\quad + \sum_{c \in U2} \lambda_{U2} f_{U2}(c) + \sum_{c \in U3} \lambda_{U3} f_{U3}(c) \\
 T &= \{q_i \in Q\} \\
 O2 = U2 &= \{(q_i, q_{i+1}) \in Q\} \\
 O3 = U3 &= \{(q_i, q_{i+1}, q_{i+2}) \in Q\} \\
 f_T(c) &= \log P(q_i|D) \\
 f_{O2}(c) &= \log P(\#od1(q_i, q_{i+1})|D) \\
 f_{O3}(c) &= \log P(\#od1(q_i, q_{i+1}, q_{i+2})|D) \\
 f_{U2}(c) &= \log P(\#uw8(q_i, q_{i+1})|D) \\
 f_{U3}(c) &= \log P(\#uw12(q_i, q_{i+1}, q_{i+2})|D) \\
 P(x|D) &= \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu}
 \end{aligned}$$

where μ is the smoothing parameter, and the combination of features is controlled by five parameters, λ_T , λ_{O2} , λ_{O3} , λ_{U2} , and λ_{U3} . $\#od1$ is the ordered window operator that matches adjacent terms in documents, $\#uw8$ is an unordered window operator that matches pairs of terms that occur within a window of 8 terms in documents, and $\#uw12$ is an unordered window operator that matches sets of three terms that occur within a window of 12 terms in documents. The learned settings for these parameters for each collection and query set fold are listed in the following table.

Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Robust-04								
Titles	μ	1562	1500	2178	1800	1863	1781	1500
Titles	λ_T	0.827	0.855	0.825	0.803	0.85	0.832	0.863
Titles	λ_{O2}	0.045	0.077	0.09	0.057	0.095	0.073	0.059
Titles	λ_{O3}	0.029	0.0097	0.0069	0.021	0.011	0.016	0.02
Titles	λ_{U2}	0.054	0.048	0.052	0.049	0.031	0.047	0.059
Titles	λ_{U3}	0.045	0.0097	0.025	0.071	0.013	0.033	0.0
Desc.	μ	3591	4247	2907	4068	3215	3606	3606
Desc.	λ_T	0.736	0.734	0.754	0.689	0.753	0.733	0.719
Desc.	λ_{O2}	0.095	0.087	0.087	0.078	0.085	0.086	0.084
Desc.	λ_{O3}	0.085	0.078	0.042	0.13	0.104	0.088	0.096
Desc.	λ_{U2}	0.043	0.044	0.032	0.047	0.024	0.038	0.047
Desc.	λ_{U3}	0.041	0.057	0.086	0.056	0.034	0.055	0.054
GOV2								
Titles	μ	2790	2170	2300	2300	2300	2372	2032
Titles	λ_T	0.867	0.853	0.88	0.835	0.856	0.858	0.831

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Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Titles	λ_{O2}	0.059	0.064	0.048	0.043	0.05	0.053	0.041
Titles	λ_{O3}	0.0049	0.0	-0.016	0.0099	-0.015	-0.0034	-0.00082
Titles	λ_{U2}	0.069	0.074	0.055	0.073	0.063	0.067	0.074
Titles	λ_{U3}	0.0	0.0095	0.034	0.039	0.046	0.026	0.054
Desc.	μ	4060	3695	4103	3964	3460	3856	3682
Desc.	λ_T	0.865	0.776	0.782	0.848	0.845	0.823	0.807
Desc.	λ_{O2}	0.077	0.073	0.078	0.107	0.107	0.088	0.088
Desc.	λ_{O3}	0.019	0.029	0.038	-0.021	0.0	0.013	0.01
Desc.	λ_{U2}	0.029	0.048	0.057	0.033	0.038	0.041	0.045
Desc.	λ_{U3}	0.0095	0.074	0.044	0.033	0.0099	0.034	0.05
ClueWeb-09-Cat-B								
Titles	μ	6630	3560	7791	7254	4800	6007	6700
Titles	λ_T	0.839	0.824	0.709	0.856	0.812	0.808	0.847
Titles	λ_{O2}	0.047	0.037	0.028	0.045	0.055	0.042	0.049
Titles	λ_{O3}	0.019	0.034	0.016	0.008	0.0078	0.017	0.015
Titles	λ_{U2}	0.086	0.047	0.215	0.074	0.066	0.097	0.079
Titles	λ_{U3}	0.0095	0.06	0.033	0.018	0.059	0.036	0.01
Desc.	μ	2992	3896	2780	2930	3616	3243	4016
Desc.	λ_T	0.851	0.895	0.953	0.864	0.868	0.886	0.898
Desc.	λ_{O2}	0.04	0.012	0.044	0.047	0.091	0.047	0.011
Desc.	λ_{O3}	0.0	0.019	-0.015	-0.013	-0.057	-0.013	0.021
Desc.	λ_{U2}	0.072	0.031	0.017	0.039	0.04	0.04	0.034
Desc.	λ_{U3}	0.037	0.043	0.0	0.063	0.058	0.04	0.036

3.6 Sequential Dependence Model Variant: Uni+O234+U234

The ranking function for the Uni+O234+U234 variant of the sequential dependence model [5] is defined as:

$$\begin{aligned}
 P(D|Q) &\stackrel{\text{rank}}{=} \sum_{c \in C(Q)} \lambda_C f_C(c) \\
 &= \sum_{c \in T} \lambda_T f_T(c) + \sum_{c \in O} \lambda_{O2} f_{O2}(c) + \sum_{c \in O3} \lambda_{O3} f_{O3}(c) + \sum_{c \in O4} \lambda_{O4} f_{O4}(c) \\
 &\quad + \sum_{c \in U2} \lambda_{U2} f_{U2}(c) + \sum_{c \in U3} \lambda_{U3} f_{U3}(c) + \sum_{c \in U4} \lambda_{U4} f_{U4}(c) \\
 T &= \{q_i \in Q\} \\
 O2 = U2 &= \{(q_i, q_{i+1}) \in Q\} \\
 O3 = U3 &= \{(q_i, q_{i+1}, q_{i+2}) \in Q\} \\
 O4 = U4 &= \{(q_i, q_{i+1}, q_{i+2}, q_{i+3}) \in Q\} \\
 f_T(c) &= \log P(q_i|D) \\
 f_{O2}(c) &= \log P(\#od1(q_i, q_{i+1})|D) \\
 f_{O3}(c) &= \log P(\#od1(q_i, q_{i+1}, q_{i+2})|D) \\
 f_{O4}(c) &= \log P(\#od1(q_i, q_{i+1}, q_{i+2}, q_{i+3})|D) \\
 f_{U2}(c) &= \log P(\#uw8(q_i, q_{i+1})|D) \\
 f_{U3}(c) &= \log P(\#uw12(q_i, q_{i+1}, q_{i+2})|D) \\
 f_{U4}(c) &= \log P(\#uw16(q_i, q_{i+1}, q_{i+2}, q_{i+3})|D) \\
 P(x|D) &= \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu}
 \end{aligned}$$

where μ is the smoothing parameter, and the combination of features is controlled by five parameters, λ_T , λ_{O2} , λ_{O3} , λ_{O4} , λ_{U2} , λ_{U3} , and λ_{U4} . $\#od1$ is the ordered window operator that matches adjacent terms in documents, $\#uw8$ is a unordered window operator that matches pairs of terms that occur within a window of 8 terms in documents, $\#uw12$ is a unordered window operator that matches sets of three terms that occur within a window of 12 terms in documents, and $\#uw16$ is a unordered window operator that matches sets of four terms that occur within a window of 16 terms in documents. We did not learn parameters for title queries for this model. This is because almost no title queries contain four or more terms, so the optimal parameter settings are nearly identical to Uni+O23+u23, detailed above. The learned settings for these parameters for each collection and query set fold are listed in the following table.

Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Robust-04								
Desc.	μ	4069	3501	3724	3643	3765	3740	2788
Desc.	λ_T	0.671	0.804	0.71	0.701	0.717	0.721	0.802
Desc.	λ_{O2}	0.105	0.093	0.087	0.079	0.082	0.089	0.109
Desc.	λ_{O3}	0.04	0.018	0.042	0.083	0.096	0.056	0.043
Desc.	λ_{O4}	0.118	0.018	0.0	0.0098	0.012	0.032	-0.0083
Desc.	λ_{U2}	0.034	0.053	0.052	0.051	0.032	0.044	0.013

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Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Desc.	λ_{U3}	0.033	0.02	0.089	0.075	0.034	0.05	0.041
Desc.	λ_{U4}	-0.0012	-0.0058	0.019	0.00047	0.027	0.008	0.0
GOV2								
Desc.	μ	3674	2998	4060	4452	3809	3798	4508
Desc.	λ_T	0.851	0.859	0.878	0.817	0.825	0.846	0.826
Desc.	λ_{O2}	0.075	0.06	0.091	0.074	0.106	0.081	0.086
Desc.	λ_{O3}	0.022	-0.004	0.0	0.013	0.014	0.0091	0.0094
Desc.	λ_{O4}	-0.0019	-0.0052	0.0038	0.012	-0.016	-0.0015	0.00034
Desc.	λ_{U2}	0.033	0.032	0.028	0.043	0.024	0.032	0.036
Desc.	λ_{U3}	0.023	0.051	0.0	0.013	0.026	0.023	0.035
Desc.	λ_{U4}	-0.0031	0.0063	0.0	0.028	0.021	0.01	0.008
ClueWeb-09-Cat-B								
Desc.	μ	2860	2952	2495	2595	4560	3092	2880
Desc.	λ_T	0.91	0.798	0.912	0.932	0.815	0.873	0.933
Desc.	λ_{O2}	0.029	0.013	0.022	0.012	0.054	0.026	0.039
Desc.	λ_{O3}	0.0078	0.0054	-0.00063	-0.0071	-0.032	-0.0054	-0.012
Desc.	λ_{O4}	0.0	0.012	-0.0019	-0.0012	0.012	0.0042	0.0081
Desc.	λ_{U2}	0.065	0.097	0.072	0.05	0.067	0.07	0.037
Desc.	λ_{U3}	0.0	0.073	0.0057	0.014	0.067	0.032	0.0
Desc.	λ_{U4}	-0.012	0.0018	-0.0089	0.0012	0.017	-0.00019	-0.004

3.7 Weighted Sequential Dependence Model

The ranking function for the weighted sequential dependence model [2] is defined as:

$$\begin{aligned}
P(Q|D) &\stackrel{\text{rank}}{=} \sum_{c \in C(Q)} \lambda_C f_C(c) \\
&= \sum_{c \in T} \lambda_T(c) f_T(c) + \sum_{c \in O} \lambda_O(c) f_O(c) + \sum_{c \in U} \lambda_U(c) f_U(c) \\
T &= \{q_i \in Q\} \\
O = U &= \{(q_i, q_{i+1}) \in Q\} \\
f_T(c) &= \log P(q_i|D) \\
f_O(c) &= \log P(\#od1(q_i, q_{i+1})|D) \\
f_U(c) &= \log P(\#uw8(q_i, q_{i+1})|D) \\
P(x|D) &= \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu} \\
\lambda_T(q_i) &= \sum_{j \in K_1} w_j^1 \cdot g_j^1(q_i) \\
\lambda_O(q_i, q_{i+1}) &= \lambda_U(q_i, q_{i+1}) = \sum_{j \in K_2} w_j^2 \cdot g_j^2(q_i, q_{i+1})
\end{aligned}$$

where μ is the smoothing parameter. The weight of each term and bi-term feature is determined as the weighted sum of a set of term or bi-term features. The set of feature

functions are defined as:

$$\begin{aligned}
g_1^1(t) &= c^1 = 1 \\
g_2^1(t) &= cf^1(t) \\
g_3^1(t) &= dc^1(t) \\
g_4^1(t) &= Gcf^1(t) \\
g_5^1(t) &= Mcf^1(t) \\
g_6^1(t) &= Wcf^1(t) \\
g_1^2(t_i, t_j) &= c^2 = 1 \\
g_2^2(t_i, t_j) &= cf^2(\#od1(t_i, t_j)) \\
g_3^2(t_i, t_j) &= dc^2(\#od1(t_i, t_j)) \\
g_4^2(t_i, t_j) &= Gcf^2(\#od1(t_i, t_j)) \\
g_5^2(t_i, t_j) &= Mcf^2(\#od1(t_i, t_j)) \\
g_6^2(t_i, t_j) &= Wcf^2(\#od1(t_i, t_j))
\end{aligned}$$

where c is the constant 1; cf is a function that returns the collection frequency of the term or bigram in the target collection; dc is a function that returns the number of documents in which the term or bigram occurs, in the target collection; Gcf is a function that returns the frequency of the term or bigram in the Google- n -grams collection; Mcf is a function that returns the frequency of the term or bigram in the MSN query log; and Wcf is a function that returns the frequency of the term or bigram in the set of all Wikipedia titles. $\#od1$ is the ordered window operator that matches adjacent terms in documents, $\#uw8$ is a unordered window operator that matches pairs of terms that occur within a window of 8 terms in documents. There are 13 parameters for this model, the smoothing parameter μ , 6 weights (w_j^1) for each of the term statistic functions (g_j^1), and 6 weights (w_j^2) for each of the bigram statistic functions (g_j^2). The learned settings for these parameters for each collection and query set fold are listed in the following table.

Param.	1	2	3	4	5	Avg.	Oracle
Robust-04, Topic Titles							
μ	1500	1500	1780	1500	1490	1554	1500
w_c^1	0.863	0.863	0.713	0.863	0.863	0.833	0.863
w_{dc}^1	-0.085	-0.085	-0.076	-0.085	-0.085	-0.083	-0.085
w_{cf}^1	0.03	0.03	0.03	0.03	0.029	0.03	0.03
w_{Gcf}^1	0.0	0.0	0.002	0.0	0.0	0.0004	0.0
w_{Mcf}^1	0.0	0.0	0.001	0.0	0.001	0.0004	0.0
w_{Wcf}^1	0.0	0.0	0.0	0.0	0.002	0.0004	0.0
w_c^2	0.049	0.049	0.049	0.049	0.049	0.049	0.049
w_{dc}^2	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
w_{cf}^2	0.0042	0.0042	0.0043	0.0042	0.0042	0.0042	0.0042
w_{Gcf}^2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
w_{Mcf}^2	0.0	0.0	0.001	0.004	0.004	0.0018	0.0

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Param.	1	2	3	4	5	Avg.	Oracle
w_{Wcf}^2	0.0	0.0	0.0	-0.001	-0.001	-0.0004	0.0
Robust-04, Topic Descriptions							
μ	1580	1790	1800	1830	1850	1770	1820
w_c^1	0.823	0.703	0.693	0.693	0.623	0.707	0.683
w_{dc}^1	-0.091	-0.078	-0.079	-0.075	-0.077	-0.08	-0.076
w_{cf}^1	0.025	0.031	0.03	0.031	0.031	0.029	0.029
w_{Gcf}^1	-0.002	0.0	-0.001	0.0	0.001	-0.0004	-0.001
w_{Mcf}^1	0.005	0.001	0.006	0.0	0.0	0.0024	0.0
w_{Wcf}^1	0.01	0.003	0.001	-0.001	0.01	0.0046	0.006
w_c^2	0.039	0.049	0.049	0.049	0.049	0.047	0.049
w_{dc}^2	0.0	-0.003	-0.001	-0.001	-0.002	-0.0014	-0.001
w_{cf}^2	0.0032	0.0043	0.0043	0.0043	0.0023	0.0037	0.0043
w_{Gcf}^2	0.0	0.001	-0.001	0.0	0.0	0.0	0.0
w_{Mcf}^2	0.004	0.001	0.004	0.004	0.004	0.0034	0.004
w_{Wcf}^2	0.005	0.0	0.004	0.0	0.0	0.0018	-0.001
GOV2, Topic Titles							
μ	2069	2109	2089	1818	2109	2039	2099
w_c^1	0.783	0.793	0.793	0.787	0.793	0.789	0.783
w_{dc}^1	-0.05	-0.051	-0.05	-0.026	-0.05	-0.046	-0.052
w_{cf}^1	0.022	0.024	0.023	0.00022	0.023	0.019	0.023
w_{Gcf}^1	-0.002	-0.001	0.0	-2.6e-05	0.0	-0.00061	0.0
w_{Mcf}^1	0.001	0.001	0.0	0.0015	0.0	0.0007	0.002
w_{Wcf}^1	0.007	-0.001	0.0	0.00091	0.0	0.0014	0.0
w_c^2	0.049	0.049	0.049	0.082	0.049	0.056	0.049
w_{dc}^2	0.0029	0.0019	0.0019	-7.3e-06	0.0019	0.0017	0.0019
w_{cf}^2	-0.0026	-0.0016	-0.0016	-0.0046	-0.0016	-0.0024	-0.0016
w_{Gcf}^2	0.0	0.0	0.0	-8.1e-05	0.0	-1.6e-05	0.0
w_{Mcf}^2	-0.001	0.003	0.001	0.0026	0.0	0.0011	0.001
w_{Wcf}^2	0.0	-0.002	0.001	0.00038	0.0	-0.00012	0.0
GOV2, Topic Descriptions							
μ	2780	2910	2760	3080	3361	2978	2489
w_c^1	0.57	0.76	0.71	0.523	0.88	0.688	0.763
w_{dc}^1	-0.037	-0.018	-0.035	-0.059	-0.044	-0.039	-0.054
w_{cf}^1	-0.002	-0.014	-0.007	0.027	-0.00081	0.00059	0.01
w_{Gcf}^1	-0.004	-0.017	-0.004	-0.003	-0.014	-0.0084	-0.001
w_{Mcf}^1	0.012	0.001	0.009	-0.001	0.009	0.006	0.002
w_{Wcf}^1	0.01	0.025	0.003	0.014	0.012	0.013	0.006
w_c^2	0.01	0.03	0.02	0.049	0.04	0.03	0.039
w_{dc}^2	0.0	-0.001	0.0	-0.002	-0.0025	-0.0011	-0.00014
w_{cf}^2	-0.001	-0.004	-0.002	-0.0014	6.6e-05	-0.0017	-0.0036
w_{Gcf}^2	0.001	0.004	0.001	0.0	0.001	0.0014	0.001
w_{Mcf}^2	-0.001	-0.003	0.001	-0.002	0.003	-0.0004	0.0
w_{Wcf}^2	0.005	0.004	0.003	0.006	0.004	0.0044	0.005
ClueWeb-09-Cat-B, Topic Titles							
μ	3461	3471	6260	4118	4204	4303	4050
w_c^1	0.88	0.88	0.79	0.795	0.644	0.798	0.79
w_{dc}^1	-0.029	-0.031	0.001	0.0011	-9.4e-05	-0.011	-0.005
w_{cf}^1	0.00042	-0.00075	0.002	-0.00062	0.00018	0.00024	0.0
w_{Gcf}^1	-0.001	0.0	-0.032	0.00015	-0.00077	-0.0067	0.005

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Param.	1	2	3	4	5	Avg.	Oracle
w_{Mcf}^1	-0.001	0.0	0.0	-0.00087	-5.4e-05	-0.00038	-0.034
w_{Wcf}^1	0.0	0.0	-0.002	0.0012	-1.8e-05	-0.00017	-0.001
w_c^2	0.08	0.07	0.02	0.088	0.074	0.067	0.01
w_{dc}^2	-0.00097	-0.00097	0.001	-2.4e-05	-0.00053	-0.0003	0.002
w_{cf}^2	0.0006	0.00037	0.0	0.00046	0.00042	0.00037	0.008
w_{Gcf}^2	0.0	0.0	0.001	0.0013	0.0003	0.00051	-0.002
w_{Mcf}^2	0.0	0.0	0.0	0.00027	-0.00015	2.4e-05	-0.004
w_{Wcf}^2	-0.007	0.0	-0.004	-0.00062	0.0007	-0.0022	0.001
ClueWeb-09-Cat-B, Topic Descriptions							
μ	3401	3134	1940	4150	4050	3335	3431
w_c^1	0.87	0.804	0.703	0.81	0.863	0.81	0.84
w_{dc}^1	-0.049	-0.054	-0.084	-0.032	-0.089	-0.062	-0.047
w_{cf}^1	-0.00057	-0.002	0.029	-0.01	0.046	0.012	-0.0017
w_{Gcf}^1	-0.001	0.00034	-0.004	0.0	-0.008	-0.0025	0.0
w_{Mcf}^1	0.002	0.013	0.033	-0.002	0.001	0.0093	0.001
w_{Wcf}^1	0.0	-5e-05	0.0	-0.002	0.0	-0.00041	0.0
w_c^2	0.06	0.082	0.039	0.01	0.029	0.044	0.04
w_{dc}^2	-0.0043	-0.0063	-0.003	0.0	-0.002	-0.0031	-0.0021
w_{cf}^2	-0.00011	-0.00049	0.0043	0.0	0.0003	0.0008	-0.001
w_{Gcf}^2	0.0	0.00028	-0.003	0.0	0.0	-0.00054	0.0
w_{Mcf}^2	0.002	0.0058	0.004	0.004	0.004	0.004	0.004
w_{Wcf}^2	0.005	9.5e-05	-0.001	0.002	0.0	0.0012	0.0

3.8 Weighted Sequential Dependence Model, Internal Variant

The ranking function for the internal variant of the weighted sequential dependence model [2] is defined as:

$$\begin{aligned}
 P(Q|D) &\stackrel{\text{rank}}{=} \sum_{c \in \mathcal{C}(Q)} \lambda_C f_C(c) \\
 &= \sum_{c \in T} \lambda_T(c) f_T(c) + \sum_{c \in O} \lambda_O(c) f_O(c) + \sum_{c \in U} \lambda_U(c) f_U(c)
 \end{aligned}$$

$$T = \{q_i \in Q\}$$

$$O = U = \{(q_i, q_{i+1}) \in Q\}$$

$$f_T(c) = \log P(q_i|D)$$

$$f_O(c) = \log P(\#od1(q_i, q_{i+1})|D)$$

$$f_U(c) = \log P(\#uw8(q_i, q_{i+1})|D)$$

$$P(x|D) = \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu}$$

$$\lambda_T(q_i) = \sum_{j \in K_1} w_j^1 \cdot g_j^1(q_i)$$

$$\lambda_O(q_i, q_{i+1}) = \lambda_U(q_i, q_{i+1}) = \sum_{j \in K_2} w_j^2 \cdot g_j^2(q_i, q_{i+1})$$

where μ is the smoothing parameter. The weight of each term and bi-term feature is determined as the weighted sum of a set of term or bi-term features. The set of feature functions are defined as:

$$\begin{aligned}
g_1^1(t) &= c^1 = 1 \\
g_2^1(t) &= cf^1(t) \\
g_3^1(t) &= dc^1(t) \\
g_1^2(t_i, t_j) &= c^2 = 1 \\
g_2^2(t_i, t_j) &= cf^2(\#od1(t_i, t_j)) \\
g_3^2(t_i, t_j) &= dc^2(\#od1(t_i, t_j))
\end{aligned}$$

where c is the constant 1; cf is a function that returns the collection frequency of the term or bigram in the target collection; and dc is a function that returns the number of documents in which the term or bigram occurs, in the target collection. $\#od1$ is the ordered window operator that matches adjacent terms in documents, $\#ww8$ is a unordered window operator that matches pairs of terms that occur within a window of 8 terms in documents. There are 7 parameters for this model, the smoothing parameter μ , 3 weights (w_j^1) for each of the term statistic functions (g_j^1), and 3 weights (w_j^2) for each of the bigram statistic functions (g_j^2). The learned settings for these parameters for each collection and query set fold are listed in the following table.

Param.	1	2	3	4	5	Avg.	Oracle
Robust-04, Topic Titles							
μ	1530	1477	1487	2099	1467	1612	1500
w_c^1	0.873	0.651	0.651	0.793	0.571	0.707	0.863
w_{dc}^1	-0.085	-0.035	-0.033	-0.049	-0.033	-0.047	-0.085
w_{cf}^1	0.031	-0.0078	-0.0068	0.00031	-0.0068	0.0019	0.03
w_c^2	0.049	0.029	0.019	0.039	0.019	0.031	0.049
w_{dc}^2	0.004	-0.0015	0.0005	0.0039	-0.0015	0.0011	-0.001
w_{cf}^2	-0.0028	0.0061	0.0071	0.0013	0.0071	0.0038	0.0042
Robust-04, Topic Descriptions							
μ	2089	1520	1467	1490	1540	1621	1790
w_c^1	0.793	0.804	0.651	0.804	0.873	0.785	0.703
w_{dc}^1	-0.049	-0.048	-0.033	-0.054	-0.093	-0.055	-0.075
w_{cf}^1	0.00035	-0.0028	-0.0068	0.0012	0.03	0.0043	0.031
w_c^2	0.039	0.056	0.019	0.016	0.049	0.036	0.049
w_{dc}^2	0.0029	-0.0021	0.00065	0.0039	0.0	0.0011	-0.001
w_{cf}^2	0.0033	0.0053	0.0071	0.0043	0.0042	0.0048	0.0043
GOV2, Topic Titles							
μ	2180	2331	2130	1820	1830	2058	2109
w_c^1	0.81	0.827	0.81	0.853	0.913	0.842	0.793
w_{dc}^1	-0.018	-0.038	-0.017	-0.068	-0.069	-0.042	-0.05
w_{cf}^1	-0.008	0.006	-0.003	0.031	0.038	0.013	0.023
w_c^2	0.0	0.076	0.02	0.049	0.069	0.043	0.049
w_{dc}^2	0.009	0.00044	0.008	0.002	0.001	0.0041	0.0019
w_{cf}^2	-0.005	-0.0022	-0.005	-0.0038	-0.0028	-0.0038	-0.0016

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Param.	1	2	3	4	5	Avg.	Oracle
GOV2, Topic Descriptions							
μ	3481	2810	2729	2770	3519	3062	2780
w_c^1	0.8	0.833	0.813	0.863	0.743	0.81	0.804
w_{dc}^1	-0.037	-0.074	-0.043	-0.079	-0.058	-0.058	-0.045
w_{cf}^1	-0.0017	0.031	0.00016	0.031	0.016	0.015	0.0032
w_c^2	0.07	0.039	0.039	0.059	0.029	0.048	0.026
w_{dc}^2	-0.0033	0.0	-0.0011	-0.002	-0.00026	-0.0013	-0.0021
w_{cf}^2	0.00034	0.00017	0.00033	-0.00031	0.0013	0.00036	0.0043
ClueWeb-09-Cat-B, Topic Titles							
μ	3471	3451	3491	4317	4435	3833	3461
w_c^1	0.88	0.88	0.88	1.291	0.807	0.947	0.88
w_{dc}^1	-0.031	-0.03	-0.029	-0.032	2.8e-05	-0.024	-0.029
w_{cf}^1	-0.00061	-0.0017	-0.0017	-0.0058	0.0003	-0.0019	-0.00047
w_c^2	0.07	0.07	0.06	0.079	0.092	0.074	0.06
w_{dc}^2	-0.00097	-0.00097	-0.00097	0.0005	-0.00044	-0.00057	-0.00097
w_{cf}^2	0.0002	0.00029	0.0002	0.0011	0.0009	0.00054	0.00037
ClueWeb-09-Cat-B, Topic Descriptions							
μ	1650	1820	2149	3561	2780	2392	2877
w_c^1	0.814	0.824	0.783	0.68	0.794	0.779	0.661
w_{dc}^1	-0.044	-0.044	-0.023	-0.03	-0.044	-0.037	-0.033
w_{cf}^1	-0.0028	-0.0028	-0.024	-0.0057	-0.00084	-0.0072	-0.0058
w_c^2	0.016	0.016	0.039	0.05	0.026	0.029	0.019
w_{dc}^2	-0.0031	-0.0031	-0.0031	-0.0035	-0.0031	-0.0032	-0.0025
w_{cf}^2	0.0053	0.0053	0.0011	0.00044	0.0033	0.0031	0.0031

3.9 Weighted Sequential Dependence Model Variant: WSDM-Int-3

The ranking function for the WSDM-Int-3 variant of the weighted sequential dependence model [2] is defined as:

$$\begin{aligned}
P(Q|D) &\stackrel{\text{rank}}{=} \sum_{c \in \mathcal{C}(Q)} \lambda_C f_C(c) \\
&= \sum_{c \in T} \lambda_T(c) f_T(c) + \sum_{c \in O2} \lambda_{O2}(c) f_{O2}(c) + \sum_{c \in O3} \lambda_{O3}(c) f_{O3}(c) \\
&\quad + \sum_{c \in U2} \lambda_{U2}(c) f_{U2}(c) + \sum_{c \in U3} \lambda_{U3}(c) f_{U3}(c)
\end{aligned}$$

$$T = \{q_i \in Q\}$$

$$O2 = U2 = \{(q_i, q_{i+1}) \in Q\}$$

$$O3 = U3 = \{(q_i, q_{i+1}, q_{i+2}) \in Q\}$$

$$f_T(c) = \log P(q_i|D)$$

$$f_{O2}(c) = \log P(\#od1(q_i, q_{i+1})|D)$$

$$f_{O3}(c) = \log P(\#od1(q_i, q_{i+1}, q_{i+2})|D)$$

$$f_{U2}(c) = \log P(\#uw8(q_i, q_{i+1})|D)$$

$$f_{U3}(c) = \log P(\#uw12(q_i, q_{i+1}, q_{i+2})|D)$$

$$P(x|D) = \frac{tf_{x,D} + \mu \frac{tf_x}{|C|}}{|D| + \mu}$$

$$\lambda_T(q_i) = \sum_{j \in K_1} w_j^1 \cdot g_j^1(q_i)$$

$$\lambda_{O2}(q_i, q_{i+1}) = \lambda_{U2}(q_i, q_{i+1}) = \sum_{j \in K_2} w_j^2 \cdot g_j^2(q_i, q_{i+1})$$

$$\lambda_{O3}(q_i, q_{i+1}, q_{i+2}) = \lambda_{U3}(q_i, q_{i+1}, q_{i+2}) = \sum_{j \in K_3} w_j^3 \cdot g_j^3(q_i, q_{i+1}, q_{i+2})$$

where μ is the smoothing parameter. The weight of each term, 2-term, and 3-gram feature is determined as the weighted sum of a set of term or bi-term features. The set of feature functions are defined as:

$$g_1^1(t) = c^1 = 1$$

$$g_2^1(t) = cf^1(t)$$

$$g_3^1(t) = dc^1(t)$$

$$g_1^2(t_i, t_j) = c^2 = 1$$

$$g_2^2(t_i, t_j) = cf^2(\#od1(t_i, t_j))$$

$$g_3^2(t_i, t_j) = dc^2(\#od1(t_i, t_j))$$

$$g_1^3(t_i, t_j, t_k) = c^3 = 1$$

$$g_2^3(t_i, t_j, t_k) = cf^3(\#od1(t_i, t_j, t_k))$$

$$g_3^3(t_i, t_j, t_k) = dc^3(\#od1(t_i, t_j, t_k))$$

where c is the constant 1; cf is a function that returns the collection frequency of the term, bigram or trigram in the target collection; and dc is a function that returns the number of documents in which the term, bigram or trigram occurs, in the target collection. $\#od1$ is the ordered window operator that matches adjacent sets of terms in documents, $\#uw8$ is a unordered window operator that matches pairs of terms that occur within a window of 8 terms in documents, and $\#uw12$ is a unordered window operator that matches sets of three terms that occur within a window of 12 terms in documents. There are 10 parameters for this model, the smoothing parameter μ , 3 weights (w_j^1) for each of the term statistic functions (g_j^1), 3 weights (w_j^2) for each of the bigram statistic functions (g_j^2), and 3 weights (w_j^3) for each of the trigram statistic functions (g_j^3). The learned settings for these parameters for each collection and query set fold are listed in the following table.

Param.	1	2	3	4	5	Avg.	Oracle
Robust-04, Topic Titles							
μ	1760	1510	1530	1510	1510	1564	1510
w_c^1	0.683	0.863	0.863	0.863	0.863	0.827	0.863
w_{dc}^1	-0.075	-0.085	-0.085	-0.085	-0.085	-0.083	-0.085
w_{cf}^1	0.031	0.03	0.031	0.03	0.03	0.03	0.03
w_c^2	0.039	0.049	0.049	0.049	0.049	0.047	0.049
w_{dc}^2	-0.003	-0.001	-0.001	-0.001	-0.001	-0.0014	-0.001
w_{cf}^2	0.0043	0.0052	0.0062	0.0052	0.0052	0.0052	0.0052
w_c^3	-0.01	-0.01	0.0	-0.01	-0.01	-0.008	-0.01
w_{dc}^3	0.001	0.0	0.0	0.001	0.001	0.0006	0.001
w_{cf}^3	0.031	0.032	0.001	0.018	0.018	0.02	0.018
Robust-04, Topic Descriptions							
μ	1500	1790	1810	1800	1810	1742	1800
w_c^1	0.883	0.703	0.703	0.713	0.703	0.741	0.703
w_{dc}^1	-0.093	-0.075	-0.075	-0.075	-0.075	-0.079	-0.076
w_{cf}^1	0.031	0.03	0.031	0.03	0.031	0.03	0.031
w_c^2	0.049	0.049	0.049	0.039	0.039	0.045	0.039
w_{dc}^2	-0.001	-0.003	-0.001	0.0	-0.001	-0.0012	0.001
w_{cf}^2	0.0062	0.0053	0.0043	0.0053	0.0053	0.0053	0.0043
w_c^3	0.0	0.01	0.0	0.01	0.01	0.006	0.01
w_{dc}^3	0.008	0.007	0.0	0.0	0.009	0.0048	0.0
w_{cf}^3	-0.001	-0.001	-0.002	0.001	0.001	-0.0004	0.0
GOV2, Topic Titles							
μ	2099	2460	2191	2221	2150	2224	2130
w_c^1	0.823	0.663	0.87	0.89	0.923	0.833	0.643
w_{dc}^1	-0.051	-0.073	-0.03	-0.025	-0.068	-0.049	-0.088
w_{cf}^1	0.02	0.044	-0.00033	-0.005	0.032	0.018	0.064
w_c^2	0.069	0.061	0.05	0.07	0.059	0.062	0.059
w_{dc}^2	-6.6e-05	-0.005	-0.0021	-0.0033	-0.001	-0.0023	-0.002
w_{cf}^2	-0.0019	0.0033	0.0039	0.00044	0.00026	0.0012	-0.0004
w_c^3	0.02	0.01	0.03	0.05	0.02	0.026	0.02
w_{dc}^3	0.0	0.001	-0.001	-0.005	-0.001	-0.0012	-0.001
w_{cf}^3	-0.001	-0.002	0.0	0.0	-0.002	-0.001	0.0
GOV2, Topic Descriptions							
μ	3110	3030	2780	3471	3410	3160	3080
w_c^1	0.623	0.743	0.863	0.85	0.784	0.772	0.703
w_{dc}^1	-0.044	-0.059	-0.093	-0.037	-0.045	-0.056	-0.069

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Param.	1	2	3	4	5	Avg.	Oracle
w_{cf}^1	0.015	0.023	0.044	-0.007	0.0022	0.015	0.031
w_c^2	0.039	0.029	0.029	0.04	0.026	0.033	0.039
w_{dc}^2	-0.004	-0.003	-0.004	-0.0013	-0.0021	-0.0029	-0.008
w_{cf}^2	0.0023	0.0043	0.0042	0.00082	0.0033	0.003	0.0063
w_c^3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
w_{dc}^3	0.0	0.0	-0.003	0.0	0.002	-0.0002	0.002
w_{cf}^3	0.002	0.0	0.004	0.002	-0.001	0.0014	-0.001
ClueWeb-09-Cat-B, Topic Titles							
μ	3461	2867	5796	6868	4050	4609	3140
w_c^1	0.87	0.691	0.485	0.812	0.16	0.603	1.323
w_{dc}^1	-0.029	-0.025	0.001	-0.00012	0.001	-0.01	-0.075
w_{cf}^1	-0.001	-0.0068	-0.0013	0.00027	-0.006	-0.003	0.03
w_c^2	0.06	0.029	0.091	0.083	0.01	0.055	0.079
w_{dc}^2	-0.0015	-0.0035	-0.0013	0.00064	0.0	-0.0011	-0.008
w_{cf}^2	0.00037	0.0021	-0.0051	0.0011	0.0	-0.00031	0.0053
w_c^3	0.02	0.01	0.038	0.067	0.0	0.027	-0.02
w_{dc}^3	0.0	0.001	0.00093	-8.8e-05	0.0	0.00037	0.003
w_{cf}^3	0.002	0.001	-9.8e-05	0.00064	0.001	0.00091	0.008
ClueWeb-09-Cat-B, Topic Descriptions							
μ	3170	4070	3027	4370	2790	3485	2937
w_c^1	0.763	0.783	0.621	0.723	0.794	0.736	0.681
w_{dc}^1	-0.069	-0.085	-0.033	-0.084	-0.044	-0.063	-0.031
w_{cf}^1	0.031	0.045	-0.0058	0.047	0.0032	0.024	-0.0048
w_c^2	0.039	0.029	0.012	0.039	0.026	0.029	0.012
w_{dc}^2	0.0	-0.003	-0.0025	-0.005	-0.0061	-0.0033	-0.0035
w_{cf}^2	-0.0037	-3.6e-05	0.0021	0.0023	0.0043	0.00098	0.0031
w_c^3	0.01	0.0	0.0	0.01	0.01	0.006	0.0
w_{dc}^3	0.001	0.0	0.0	0.002	0.0	0.0006	0.001
w_{cf}^3	0.0	0.005	0.0	-0.004	0.001	0.0004	0.0

3.10 PLM

The ranking function for best-position PLM [4] is defined as:

$$P(D|Q) = \max_{j < |D|} \left(\frac{\sum_{q_i \in Q} c'(q_i, j) + \mu \cdot \frac{cf_{q_i}}{|C|}}{Z_j + \mu} \right)$$

$$c'(q_i, j) = \sum_{k=1}^{|D|} c(w, k) \cdot k(k, j)$$

$$Z_j = \sum_{k=1}^{|D|} k(j, k)$$

$$k(j, k) = \exp\left(\frac{-(j-k)^2}{2\sigma^2}\right)$$

This formulation is the best-position strategy, using the Gaussian kernel. The parameters for the model are μ and σ . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Robust-04								
Titles	μ	632	517	748	894	891	737	741
Titles	σ	387.183	294.084	2664	1389	389.238	1025	566
Desc.	μ	3389	2734	3090	3190	3060	3093	3093
Desc.	σ	173.065	129.727	170.0	166.179	150.0	157.794	157.794
GOV2								
Titles	μ	632	517	748	894	891	737	741
Titles	σ	387.183	294.084	2664	1389	389.238	1025	566
Desc.	μ	3389	2734	3090	3190	3060	3093	3093
Desc.	σ	173.065	129.727	170.0	166.179	150.0	157.794	157.794
ClueWeb-09-Cat-B								
Titles	μ	632	517	748	894	891	737	741
Titles	σ	387.183	294.084	2664	1389	389.238	1025	566
Desc.	μ	3389	2734	3090	3190	3060	3093	3093
Desc.	σ	173.065	129.727	170.0	166.179	150.0	157.794	157.794

3.11 PLM-2

The ranking function for PLM-2 [4] is defined as:

$$\begin{aligned}
P(D|Q) &= \lambda \cdot \max_{j < |D|} \left(\sum_{q_i \in Q} \frac{c'(q_i, j) + \mu \cdot \frac{cf_{q_i}}{|C|}}{Z_j + \mu} \right) \\
&\quad + (1 - \lambda) \cdot \left(\frac{tf_{q_i, D} + \mu \cdot \frac{cf_{q_i}}{|C|}}{|D| + \mu} \right) \\
c'(q_i, j) &= \sum_{k=1}^{|D|} c(w, k) \cdot k(k, j) \\
Z_j &= \sum_{k=1}^{|D|} k(j, k) \\
k(j, k) &= \exp \left(\frac{-(j - k)^2}{2\sigma^2} \right)
\end{aligned}$$

This is the multi- σ strategy, using the Gaussian kernel. The second kernel is specified with σ_2 set to ∞ , which is rank equivalent to the query likelihood model. The parameters for the model are μ and σ . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Robust-04								
Titles	λ	0.39	0.389	0.363	0.4	0.425	0.394	0.358
Titles	μ	934	1323	1199	690	1040	1037	873
Titles	σ	17.426	31.95	10.184	-30.0	-7.9	4.332	9.296
Desc.	λ	0.48	0.564	0.531	0.489	0.473	0.507	0.507
Desc.	μ	1649	1936	2083	2029	2250	1989	1989
Desc.	σ	12.58	11.808	13.352	-11.0	12.328	7.782	11.674

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Query Set	Param.	1	2	3	4	5	Avg.	Oracle
GOV2								
Titles	λ	0.39	0.389	0.363	0.4	0.425	0.394	0.358
Titles	μ	934	1323	1199	690	1040	1037	873
Titles	σ	17.426	31.95	10.184	-30.0	-7.9	4.332	9.296
Desc.	λ	0.48	0.564	0.531	0.489	0.473	0.507	0.507
Desc.	μ	1649	1936	2083	2029	2250	1989	1989
Desc.	σ	12.58	11.808	13.352	-11.0	12.328	7.782	11.674
ClueWeb-09-Cat-B								
Titles	λ	0.39	0.389	0.363	0.4	0.425	0.394	0.358
Titles	μ	934	1323	1199	690	1040	1037	873
Titles	σ	17.426	31.95	10.184	-30.0	-7.9	4.332	9.296
Desc.	λ	0.48	0.564	0.531	0.489	0.473	0.507	0.507
Desc.	μ	1649	1936	2083	2029	2250	1989	1989
Desc.	σ	12.58	11.808	13.352	-11.0	12.328	7.782	11.674

3.12 PL2

The ranking function for the PL2 model [1] is defined as:

$$score_{PL2}(Q, D) = \sum_{q_i \in Q} \frac{1}{tfn_{q_i} + 1} \cdot \left(tfn_{q_i} \cdot \log_2 \left(\frac{1}{\lambda_{q_i}} \right) + \frac{\lambda_{q_i}}{\log_2(e)} + \frac{1}{2} \cdot \log_2(2 \cdot \pi \cdot tfn_{q_i}) + tfn_{q_i} \cdot \left(\log_2(tfn_{q_i}) - \frac{1}{\log_2(e)} \right) \right)$$

$$\lambda_{q_i} = \frac{cf_{q_i}}{|\mathcal{C}_D|}$$

$$tfn_{q_i} = tf_{q_i, D} \cdot \log_2 \left(1.0 + c \cdot \frac{|D_{avg}|}{|D|} \right)$$

where $|\mathcal{C}_D|$ is the number of documents in the collection and $|D_{avg}|$ is the average document length for the collection. This formulation is extracted from the canonical implementation of the model [6]. The only parameter of the model is c . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	c	9.19	9.14	9.06	9.32	9.05	9.15	9.2
Rob-04	Desc.	c	2.14	2.17	2.1	2.09	2.38	2.18	2.09
GOV2	Titles	c	7.94	6.76	7.95	7.22	7.93	7.56	7.96
GOV2	Desc.	c	3.85	4.31	3.83	4.3	3.92	4.04	3.94
Clue-B	Titles	c	19.1	15.4	15.6	15.4	18.3	16.8	16.9
Clue-B	Desc.	c	5.46	11.8	5.86	5.89	5.47	6.89	5.48

3.13 pDFR-BiL2

The ranking function for the pDFR-BiL2 model [7] is defined as:

$$score_{pDFR-BiL2}(D, Q) = \lambda \cdot score_{PL2}(D, Q) + (1 - \lambda) \cdot score_{BiL2}(D, Q)$$

$$score_{BiL2}(D, Q) = \sum_{p \in Q} \frac{1}{pfn} \left(-\log_2(|D| - 1)! + \log_2(pfn)! \right. \\ \left. - pfn \cdot \log_2 \left(\frac{1}{|D| - 1} \right) \right. \\ \left. - (|D| - 1 - pfn) \cdot \log_2 \left(1 - \frac{1}{|D| - 1} \right) \right)$$

$$pfn = tf_{p,D} \cdot \left(1 + c_p \cdot \frac{|D_{avg}| - 1}{|D| - 1} \right)$$

where p is a pair of adjacent terms extracted from the query, $tf_{p,D}$ is the frequency of the pair of terms in a document, as matched by an unordered window of width 5, and $|D_{avg}|$ is the average document length for the collection. This formulation of $score_{PL2}$ is specified above. There are three parameters for the model: c , c_p , and λ . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	c	8.4	9.0	8.9	15.2	9.55	10.2	7.94
Rob-04	Titles	c_p	1649	216.0	828	54.1	209.0	591	225.0
Rob-04	Titles	λ	1.5	1.5	1.4	1.87	1.45	1.54	1.6
Rob-04	Desc.	c	1.66	1.44	1.81	2.18	2.2	1.86	1.46
Rob-04	Desc.	c_p	827	1667	222.0	436.0	6567	1944	1945
Rob-04	Desc.	λ	1.42	1.42	1.44	1.89	1.3	1.5	1.4
GOV2	Titles	c	6.91	7.81	6.67	6.66	7.79	7.17	7.17
GOV2	Titles	c_p	182.0	130.0	420.0	208.0	176.0	223.0	223.0
GOV2	Titles	λ	1.34	1.41	1.36	1.33	1.37	1.36	1.36
GOV2	Desc.	c	3.23	3.29	2.81	3.38	2.66	3.07	2.87
GOV2	Desc.	c_p	208.0	1648	591	1649	1944	1208	1208
GOV2	Desc.	λ	1.3	1.3	1.24	1.2	1.3	1.27	1.27
Clue-B	Titles	c	9.91	15.4	15.3	16.0	19.8	15.3	9.96
Clue-B	Titles	c_p	590	56.9	1947	7.38	1.0	520	1946
Clue-B	Titles	λ	1.14	1.25	1.2	0.974	1.0	1.11	1.1
Clue-B	Desc.	c	4.76	12.1	4.46	7.77	4.81	6.78	5.11
Clue-B	Desc.	c_p	1943	29.0	1944	29.5	591	907	14.5
Clue-B	Desc.	λ	1.1	0.993	1.1	0.954	1.04	1.04	0.987

3.14 pDFR-PL2

The ranking function for the pDFR-PL2 model, adapted from the pDFR-BiL2 model [7], is defined as:

$$\begin{aligned}
 score_{pDFR-BiL2}(D, Q) &= \lambda \cdot score_{PL2}(D, Q) + (1 - \lambda) \cdot score_{pPL2}(D, Q) \\
 score_{pPL2}(Q, D) &= \sum_{p \in Q} \frac{1}{pfn + 1} \cdot \\
 &\quad \left(pfn \cdot \log_2 \left(\frac{1}{\lambda_p} \right) + \frac{\lambda_p}{\log_2(e)} + \frac{1}{2} \cdot \log_2(2 \cdot \pi \cdot pfn) \right. \\
 &\quad \left. + pfn \cdot \left(\log_2(pfn) - \frac{1}{\log_2(e)} \right) \right) \\
 \lambda_p &= \frac{cf_p}{|C_D|} \\
 pfn &= tf_{p,D} \cdot \log_2 \left(1.0 + c \cdot \frac{|D_{avg}|}{|D|} \right)
 \end{aligned}$$

where p is a pair of adjacent terms extracted from the query; $tf_{p,D}$ is the frequency of the pair of terms in a document, as matched by an unordered window of width 5, cf_p is the collection frequency of the pair of terms p , $|C_D|$ is the number of documents in the collection, and $|D_{avg}|$ is the average document length for the collection. This formulation of $score_{pPL2}$ is provided above. There are three parameters for the model: c , c_p , and λ . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	c	8.89	9.25	9.8	7.85	9.05	8.97	9.9
Rob-04	Titles	c_p	30.9	4.2	13.8	24.3	13.4	17.3	14.6
Rob-04	Titles	λ	0.915	0.9	0.9	0.939	0.9	0.911	0.9
Rob-04	Desc.	c	2.4	2.35	2.15	2.78	2.75	2.49	2.4
Rob-04	Desc.	c_p	8.8	13.6	11.7	19.4	103.0	31.4	22.1
Rob-04	Desc.	λ	0.9	0.9	0.868	0.849	0.9	0.883	0.9
GOV2	Titles	c	11.9	11.4	15.0	11.1	10.4	12.0	12.0
GOV2	Titles	c_p	13.9	12.4	31.3	11.3	26.3	19.0	19.0
GOV2	Titles	λ	0.899	0.874	0.845	0.844	0.9	0.872	0.872
GOV2	Desc.	c	4.3	4.24	3.84	4.84	4.25	4.3	4.4
GOV2	Desc.	c_p	10.3	52.5	14.0	14.0	17.8	21.7	21.8
GOV2	Desc.	λ	0.9	0.9	0.9	0.9	0.902	0.9	0.9
Clue-B	Titles	c	60.3	20.9	109.0	60.2	60.2	62.1	60.1
Clue-B	Titles	c_p	3.18	0.9	3.29	1.1	1.0	1.89	1.1
Clue-B	Titles	λ	0.889	0.9	0.84	0.9	0.9	0.886	0.9
Clue-B	Desc.	c	5.59	12.3	18.8	13.3	16.8	13.4	12.5
Clue-B	Desc.	c_p	30.7	1.2	0.3	0.371	1.4	6.79	6.59
Clue-B	Desc.	λ	0.883	0.9	0.8	0.898	0.8	0.856	0.856

3.15 BM25

The ranking function for the BM25 model [9] is defined as:

$$RSV_{BM25}(Q, D) \stackrel{\text{rank}}{=} \sum_{q_i \in Q} \log \left[\frac{N}{dc_{q_i}} \right] \cdot \frac{(k_1 + 1) \cdot tf_{q_i, D}}{k_1 \left((1 - b) + b \cdot \frac{|D|}{|D_{avg}|} \right) + tf_{t, D}}$$

where $|D_{avg}|$ is the average length of a document in the collection, and dc_{q_i} is the number of documents that contain the query term, q_i . The parameters for the model are b and k_1 . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	b	0.337	0.306	0.298	0.38	0.304	0.325	0.303
Rob-04	Titles	k_1	0.664	0.693	0.77	0.675	0.737	0.708	0.725
Rob-04	Desc.	b	0.532	0.591	0.675	0.49	0.509	0.559	0.67
Rob-04	Desc.	k_1	1.25	1.03	0.781	0.981	0.936	0.996	0.892
GOV2	Titles	b	0.317	0.344	0.326	0.391	0.313	0.338	0.335
GOV2	Titles	k_1	0.864	0.929	0.873	0.91	0.952	0.906	0.873
GOV2	Desc.	b	0.442	0.449	0.468	0.46	0.445	0.453	0.44
GOV2	Desc.	k_1	1.54	1.56	1.62	1.47	1.54	1.55	1.52
Clue-B	Titles	b	0.263	0.259	0.152	0.152	0.208	0.207	0.263
Clue-B	Titles	k_1	0.918	1.06	1.66	1.85	1.62	1.42	0.991
Clue-B	Desc.	b	0.367	0.285	0.38	0.287	0.331	0.33	0.335
Clue-B	Desc.	k_1	5.06	6.54	6.21	7.07	6.68	6.31	5.82

3.16 BM25-TP

The ranking function for the BM25-TP model [8] is defined as:

$$RSV_{BM25-TP}(D, Q) = RSV_{BM25}(D, Q) + \sum_{(t_i, t_{i+1}) \in Q} w_D(t_i, t_{i+1}) \cdot \min(qw_i, qw_{i+1})$$

$$w_D(t_i, t_{i+1}) = \frac{(k_1 + t_1) \cdot \sum_{occ_D(t_i, t_{i+1})} tpi(t_i, t_{i+1})}{K + \sum_{occ_D(t_i, t_{i+1})} tpi(t_i, t_{i+1})}$$

$$tpi(t_i, t_{i+1}) = \frac{1.0}{dist(t_i, t_{i+1})^2}$$

$$K = k_1 \cdot \left((1 - b) + b \cdot \frac{|D|}{|D_{avg}|} \right)$$

This model combines the BM25 scoring function, defined above, with a score for each matched dependency. The parameters for the model are the same as for BM25, b and k_1 . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	b	0.296	0.337	0.222	0.223	0.225	0.261	0.219
Rob-04	Titles	k_1	0.552	0.701	0.792	0.791	0.748	0.717	0.763
Rob-04	Desc.	b	0.512	0.518	0.482	0.487	0.459	0.492	0.456

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Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Desc.	k_1	0.868	0.842	0.879	0.758	0.89	0.847	0.954
GOV2	Titles	b	0.196	0.201	0.206	0.219	0.199	0.204	0.216
GOV2	Titles	k_1	0.668	0.727	0.627	0.773	0.793	0.718	0.724
GOV2	Desc.	b	0.337	0.333	0.351	0.313	0.328	0.332	0.334
GOV2	Desc.	k_1	1.1	1.16	1.35	1.12	1.14	1.17	1.17
Clue-B	Titles	b	0.18	0.184	0.1	0.1	0.13	0.139	0.119
Clue-B	Titles	k_1	1.98	1.95	1.99	1.98	2.36	2.05	1.83
Clue-B	Desc.	b	0.289	0.259	0.311	0.289	0.282	0.286	0.285
Clue-B	Desc.	k_1	4.29	5.81	4.35	5.7	4.27	4.88	4.98

3.17 BM25-TP2

The ranking function for the BM25-TP2 model [12] is defined as:

$$RSV_{BM25-TP2}(D, Q) = RSV_{BM25}(D, Q) + \sum_{(t_i, t_{i+1}) \in Q} w_D(t_i, t_{i+1}) \cdot w_{i,i+1}$$

$$w_D(t_i, t_{i+1}) = \frac{(k_1 + t_1) \cdot tf_{t_i, t_{i+1}, D}}{K + tf_{t_i, t_{i+1}, D}}$$

$$K = k_1 \cdot \left((1 - b) + b \cdot \frac{|D|}{|D_{avg}|} \right)$$

where $tf_{t_i, t_{i+1}, D}$ is the frequency of the bi-gram (t_i, t_{i+1}) in document D . Similar to BM25-TP, this model combines the BM25 scoring function, defined above, with a score for each matched dependency. And again, parameters for the model are the same as for BM25, b and k_1 . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	b	0.213	0.238	0.155	0.179	0.135	0.184	0.184
Rob-04	Titles	k_1	0.668	0.918	0.982	0.728	1.28	0.914	0.914
Rob-04	Desc.	b	0.384	0.432	0.441	0.354	0.357	0.394	0.362
Rob-04	Desc.	k_1	1.39	1.43	1.28	1.21	1.27	1.32	1.27
GOV2	Titles	b	0.133	0.138	0.139	0.16	0.155	0.145	0.147
GOV2	Titles	k_1	0.782	1.16	1.17	0.71	1.33	1.03	1.26
GOV2	Desc.	b	0.183	0.174	0.206	0.192	0.18	0.187	0.182
GOV2	Desc.	k_1	1.42	2.03	1.47	1.34	1.42	1.54	1.43
Clue-B	Titles	b	0.109	0.0972	0.087	0.0902	0.129	0.102	0.11
Clue-B	Titles	k_1	2.98	5.04	3.52	3.06	4.85	3.89	5.21
Clue-B	Desc.	b	0.192	0.144	0.129	0.136	0.216	0.163	0.144
Clue-B	Desc.	k_1	4.99	6.64	9.32	7.1	5.62	6.73	6.45

3.18 BM25-Span

The ranking function for the BM25-Span model [11] is defined as:

$$RSV_{Span}(Q, D) = \sum_{q_i \in Q} \log \left[\frac{N}{dc_{q_i}} \right] \cdot \frac{(k_1 + 1) \cdot rc}{k_1 \left((1 - b) + b \cdot \frac{|D|}{|D_{avg}|} \right) + rc}$$

$$rc = \sum_{occ_j \in spans(Q, D)} \frac{n_j^\lambda}{width(occ_j)^\gamma}$$

where $|D_{avg}|$ is the average length of a document in the collection, and dc_{q_i} is the number of documents that contain the query term, q_i . $spans(Q, D)$ is the function that returns all span occurrences, occ_j , in the document. n_j is the number of query terms present in the span instance occ_j . $width(occ_j)$ is the width of the span occ_j . The width of a singleton span is defined as the maximum width (45). The parameters for the model are b , k_1 , γ and λ . The learned settings for these parameters for each collection and query set fold are listed in the following table.

Coll.	Query Set	Param.	1	2	3	4	5	Avg.	Oracle
Rob-04	Titles	b	0.3	0.31	0.279	0.29	0.258	0.287	0.311
Rob-04	Titles	k_1	0.44	0.41	0.55	0.45	0.871	0.544	0.475
Rob-04	Titles	γ	0.25	0.22	0.227	0.24	0.145	0.216	0.236
Rob-04	Titles	λ	0.54	0.52	0.647	0.52	0.662	0.578	0.475
Rob-04	Desc.	b	0.46	0.5	0.479	0.535	0.531	0.501	0.501
Rob-04	Desc.	k_1	0.74	0.57	0.866	0.695	0.554	0.685	0.685
Rob-04	Desc.	γ	0.17	0.25	0.17	0.175	0.263	0.206	0.206
Rob-04	Desc.	λ	0.44	0.4	0.494	0.354	0.538	0.445	0.465
GOV2	Titles	b	0.18	0.2	0.187	0.21	0.195	0.194	0.187
GOV2	Titles	k_1	0.584	0.574	0.653	0.615	0.598	0.605	0.644
GOV2	Titles	γ	0.312	0.312	0.315	0.295	0.337	0.314	0.316
GOV2	Titles	λ	1.335	1.305	1.308	1.212	1.208	1.274	1.308
GOV2	Desc.	b	0.307	0.331	0.341	0.321	0.347	0.33	0.331
GOV2	Desc.	k_1	1.054	1.335	1.025	1.005	1.204	1.125	1.325
GOV2	Desc.	γ	0.336	0.256	0.276	0.286	0.236	0.278	0.256
GOV2	Desc.	λ	0.878	0.745	0.655	0.695	0.638	0.722	0.725
Clue-B	Titles	b	0.27	0.15	0.074	0.12	0.135	0.15	0.12
Clue-B	Titles	k_1	3.254	0.75	3.074	1.05	1.093	1.844	1.914
Clue-B	Titles	γ	0.211	0.26	0.27	0.25	0.37	0.272	0.282
Clue-B	Titles	λ	1.487	1.16	1.538	1.2	1.141	1.305	1.305
Clue-B	Desc.	b	0.301	0.173	0.174	0.184	0.213	0.209	0.144
Clue-B	Desc.	k_1	3.885	4.561	5.885	10.855	4.921	6.021	6.425
Clue-B	Desc.	γ	0.206	0.334	0.284	0.314	0.43	0.314	0.324
Clue-B	Desc.	λ	0.735	1.1	1.074	1.254	1.29	1.09	1.284

4 Fold-level Retrieval Evaluation

In this section, we detail the evaluation metrics for each fold, retrieval model, collection, and query set. We also detail the evaluation metrics for the joint results (average

of the evaluation metric over the 5 folds), the average parameter settings, and the oracle tuned set of parameters. We present retrieval models in the same order as above.

1. query likelihood (QL);
2. the sequential dependence model (SDM);
3. SDM variant: Uni+O234;
4. SDM variant: Uni+O234+U2;
5. SDM variant: Uni+O23+U23;
6. SDM variant: Uni+O234+U234;
7. the weighted sequential dependence model (WSDM);
8. WSDM variant: WSDM-Int;
9. WSDM variant: WSDM-Int-3;
10. PLM;
11. PLM-2;
12. PL2;
13. pDFR-BiL2;
14. pDFR-PL2;
15. BM25;
16. BM25-TP;
17. BM25-TP2; and
18. BM25-Span.

Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
QL	Robust-04	Titles	0	0.261	0.402	0.361
QL	Robust-04	Titles	1	0.259	0.405	0.345
QL	Robust-04	Titles	2	0.259	0.443	0.402
QL	Robust-04	Titles	3	0.250	0.417	0.363
QL	Robust-04	Titles	4	0.231	0.394	0.356
QL	Robust-04	Titles	Joint	0.252	0.412	0.365
QL	Robust-04	Titles	Avg.	0.253	0.413	0.367
QL	Robust-04	Titles	Oracle	0.253	0.414	0.367
QL	Robust-04	Desc.	0	0.267	0.405	0.339
QL	Robust-04	Desc.	1	0.257	0.398	0.331
QL	Robust-04	Desc.	2	0.236	0.381	0.333
QL	Robust-04	Desc.	3	0.225	0.380	0.366
QL	Robust-04	Desc.	4	0.235	0.383	0.301
QL	Robust-04	Desc.	Joint	0.244	0.389	0.334
QL	Robust-04	Desc.	Avg.	0.244	0.389	0.333
QL	Robust-04	Desc.	Oracle	0.244	0.389	0.334
QL	GOV2	Titles	0	0.294	0.391	0.477
QL	GOV2	Titles	1	0.341	0.422	0.548
QL	GOV2	Titles	2	0.338	0.432	0.567
QL	GOV2	Titles	3	0.256	0.398	0.467
QL	GOV2	Titles	4	0.262	0.423	0.498
QL	GOV2	Titles	Joint	0.298	0.413	0.511
QL	GOV2	Titles	Avg.	0.298	0.415	0.512
QL	GOV2	Titles	Oracle	0.298	0.415	0.511
QL	GOV2	Desc.	0	0.210	0.329	0.374
QL	GOV2	Desc.	1	0.258	0.377	0.482
QL	GOV2	Desc.	2	0.258	0.409	0.437
QL	GOV2	Desc.	3	0.317	0.441	0.620
QL	GOV2	Desc.	4	0.240	0.333	0.447
QL	GOV2	Desc.	Joint	0.257	0.378	0.472
QL	GOV2	Desc.	Avg.	0.258	0.378	0.472
QL	GOV2	Desc.	Oracle	0.258	0.378	0.473
QL	ClueWeb-09-B	Titles	0	0.118	0.219	0.364
QL	ClueWeb-09-B	Titles	1	0.095	0.188	0.308
QL	ClueWeb-09-B	Titles	2	0.121	0.319	0.410
QL	ClueWeb-09-B	Titles	3	0.092	0.245	0.305
QL	ClueWeb-09-B	Titles	4	0.064	0.135	0.218
QL	ClueWeb-09-B	Titles	Joint	0.098	0.221	0.321
QL	ClueWeb-09-B	Titles	Avg.	0.099	0.224	0.326
QL	ClueWeb-09-B	Titles	Oracle	0.099	0.224	0.327
QL	ClueWeb-09-B	Desc.	0	0.048	0.154	0.213
QL	ClueWeb-09-B	Desc.	1	0.073	0.189	0.233
QL	ClueWeb-09-B	Desc.	2	0.107	0.223	0.264
QL	ClueWeb-09-B	Desc.	3	0.099	0.237	0.337
QL	ClueWeb-09-B	Desc.	4	0.045	0.143	0.172
QL	ClueWeb-09-B	Desc.	Joint	0.074	0.189	0.244
QL	ClueWeb-09-B	Desc.	Avg.	0.075	0.190	0.244
QL	ClueWeb-09-B	Desc.	Oracle	0.075	0.191	0.246
SDM	Robust-04	Titles	0	0.277	0.405	0.360
SDM	Robust-04	Titles	1	0.268	0.418	0.363
SDM	Robust-04	Titles	2	0.265	0.461	0.421
SDM	Robust-04	Titles	3	0.261	0.424	0.361
SDM	Robust-04	Titles	4	0.243	0.406	0.369

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
SDM	Robust-04	Titles	Joint	0.263	0.423	0.375
SDM	Robust-04	Titles	Avg.	0.264	0.423	0.375
SDM	Robust-04	Titles	Oracle	0.265	0.424	0.376
SDM	Robust-04	Desc.	0	0.276	0.413	0.350
SDM	Robust-04	Desc.	1	0.268	0.420	0.358
SDM	Robust-04	Desc.	2	0.256	0.400	0.342
SDM	Robust-04	Desc.	3	0.244	0.403	0.381
SDM	Robust-04	Desc.	4	0.246	0.395	0.315
SDM	Robust-04	Desc.	Joint	0.258	0.406	0.349
SDM	Robust-04	Desc.	Avg.	0.260	0.410	0.351
SDM	Robust-04	Desc.	Oracle	0.260	0.410	0.351
SDM	GOV2	Titles	0	0.327	0.430	0.510
SDM	GOV2	Titles	1	0.357	0.433	0.587
SDM	GOV2	Titles	2	0.361	0.479	0.626
SDM	GOV2	Titles	3	0.296	0.450	0.523
SDM	GOV2	Titles	4	0.290	0.452	0.543
SDM	GOV2	Titles	Joint	0.326	0.449	0.557
SDM	GOV2	Titles	Avg.	0.327	0.449	0.559
SDM	GOV2	Titles	Oracle	0.327	0.449	0.560
SDM	GOV2	Desc.	0	0.241	0.414	0.462
SDM	GOV2	Desc.	1	0.296	0.418	0.538
SDM	GOV2	Desc.	2	0.289	0.438	0.470
SDM	GOV2	Desc.	3	0.332	0.447	0.633
SDM	GOV2	Desc.	4	0.255	0.355	0.483
SDM	GOV2	Desc.	Joint	0.283	0.414	0.518
SDM	GOV2	Desc.	Avg.	0.284	0.414	0.517
SDM	GOV2	Desc.	Oracle	0.284	0.415	0.518
SDM	ClueWeb-09-B	Titles	0	0.128	0.266	0.412
SDM	ClueWeb-09-B	Titles	1	0.110	0.206	0.320
SDM	ClueWeb-09-B	Titles	2	0.125	0.322	0.415
SDM	ClueWeb-09-B	Titles	3	0.102	0.260	0.333
SDM	ClueWeb-09-B	Titles	4	0.075	0.140	0.238
SDM	ClueWeb-09-B	Titles	Joint	0.108	0.239	0.343
SDM	ClueWeb-09-B	Titles	Avg.	0.111	0.247	0.351
SDM	ClueWeb-09-B	Titles	Oracle	0.111	0.249	0.353
SDM	ClueWeb-09-B	Desc.	0	0.050	0.151	0.215
SDM	ClueWeb-09-B	Desc.	1	0.086	0.212	0.245
SDM	ClueWeb-09-B	Desc.	2	0.096	0.222	0.283
SDM	ClueWeb-09-B	Desc.	3	0.107	0.259	0.353
SDM	ClueWeb-09-B	Desc.	4	0.049	0.153	0.176
SDM	ClueWeb-09-B	Desc.	Joint	0.078	0.200	0.255
SDM	ClueWeb-09-B	Desc.	Avg.	0.080	0.200	0.254
SDM	ClueWeb-09-B	Desc.	Oracle	0.082	0.202	0.254
Uni+O234	Robust-04	Titles	0	0.279	0.416	0.372
Uni+O234	Robust-04	Titles	1	0.266	0.420	0.363
Uni+O234	Robust-04	Titles	2	0.266	0.462	0.419
Uni+O234	Robust-04	Titles	3	0.258	0.417	0.354
Uni+O234	Robust-04	Titles	4	0.238	0.394	0.356
Uni+O234	Robust-04	Titles	Joint	0.261	0.422	0.373
Uni+O234	Robust-04	Titles	Avg.	0.263	0.422	0.372
Uni+O234	Robust-04	Titles	Oracle	0.263	0.423	0.374
Uni+O234	Robust-04	Desc.	0	0.276	0.416	0.353

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
Uni+O234	Robust-04	Desc.	1	0.269	0.419	0.359
Uni+O234	Robust-04	Desc.	2	0.256	0.401	0.338
Uni+O234	Robust-04	Desc.	3	0.243	0.409	0.386
Uni+O234	Robust-04	Desc.	4	0.244	0.400	0.319
Uni+O234	Robust-04	Desc.	Joint	0.258	0.409	0.351
Uni+O234	Robust-04	Desc.	Avg.	0.258	0.411	0.354
Uni+O234	Robust-04	Desc.	Oracle	0.259	0.412	0.354
Uni+O234	GOV2	Titles	0	0.313	0.401	0.480
Uni+O234	GOV2	Titles	1	0.338	0.405	0.555
Uni+O234	GOV2	Titles	2	0.357	0.470	0.616
Uni+O234	GOV2	Titles	3	0.278	0.419	0.505
Uni+O234	GOV2	Titles	4	0.278	0.440	0.515
Uni+O234	GOV2	Titles	Joint	0.313	0.427	0.534
Uni+O234	GOV2	Titles	Avg.	0.316	0.430	0.533
Uni+O234	GOV2	Titles	Oracle	0.316	0.432	0.534
Uni+O234	GOV2	Desc.	0	0.236	0.397	0.448
Uni+O234	GOV2	Desc.	1	0.296	0.408	0.527
Uni+O234	GOV2	Desc.	2	0.285	0.429	0.477
Uni+O234	GOV2	Desc.	3	0.330	0.449	0.632
Uni+O234	GOV2	Desc.	4	0.247	0.352	0.472
Uni+O234	GOV2	Desc.	Joint	0.279	0.407	0.511
Uni+O234	GOV2	Desc.	Avg.	0.280	0.409	0.510
Uni+O234	GOV2	Desc.	Oracle	0.281	0.409	0.511
Uni+O234	ClueWeb-09-B	Titles	0	0.123	0.254	0.395
Uni+O234	ClueWeb-09-B	Titles	1	0.104	0.202	0.313
Uni+O234	ClueWeb-09-B	Titles	2	0.132	0.330	0.418
Uni+O234	ClueWeb-09-B	Titles	3	0.101	0.261	0.333
Uni+O234	ClueWeb-09-B	Titles	4	0.075	0.148	0.240
Uni+O234	ClueWeb-09-B	Titles	Joint	0.107	0.239	0.340
Uni+O234	ClueWeb-09-B	Titles	Avg.	0.110	0.245	0.347
Uni+O234	ClueWeb-09-B	Titles	Oracle	0.110	0.245	0.347
Uni+O234	ClueWeb-09-B	Desc.	0	0.048	0.155	0.223
Uni+O234	ClueWeb-09-B	Desc.	1	0.078	0.195	0.238
Uni+O234	ClueWeb-09-B	Desc.	2	0.092	0.205	0.248
Uni+O234	ClueWeb-09-B	Desc.	3	0.103	0.254	0.343
Uni+O234	ClueWeb-09-B	Desc.	4	0.048	0.138	0.169
Uni+O234	ClueWeb-09-B	Desc.	Joint	0.074	0.190	0.245
Uni+O234	ClueWeb-09-B	Desc.	Avg.	0.077	0.192	0.248
Uni+O234	ClueWeb-09-B	Desc.	Oracle	0.079	0.192	0.243
Uni+O234+U2	Robust-04	Titles	0	0.278	0.411	0.365
Uni+O234+U2	Robust-04	Titles	1	0.267	0.414	0.363
Uni+O234+U2	Robust-04	Titles	2	0.266	0.462	0.422
Uni+O234+U2	Robust-04	Titles	3	0.259	0.423	0.360
Uni+O234+U2	Robust-04	Titles	4	0.243	0.406	0.367
Uni+O234+U2	Robust-04	Titles	Joint	0.263	0.423	0.375
Uni+O234+U2	Robust-04	Titles	Avg.	0.264	0.424	0.376
Uni+O234+U2	Robust-04	Titles	Oracle	0.265	0.427	0.376
Uni+O234+U2	Robust-04	Desc.	0	0.277	0.415	0.348
Uni+O234+U2	Robust-04	Desc.	1	0.269	0.418	0.358
Uni+O234+U2	Robust-04	Desc.	2	0.258	0.406	0.346
Uni+O234+U2	Robust-04	Desc.	3	0.245	0.405	0.385
Uni+O234+U2	Robust-04	Desc.	4	0.247	0.398	0.317

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
Uni+O234+U2	Robust-04	Desc.	Joint	0.259	0.408	0.351
Uni+O234+U2	Robust-04	Desc.	Avg.	0.261	0.411	0.353
Uni+O234+U2	Robust-04	Desc.	Oracle	0.261	0.413	0.354
Uni+O234+U2	GOV2	Titles	0	0.328	0.432	0.517
Uni+O234+U2	GOV2	Titles	1	0.353	0.425	0.578
Uni+O234+U2	GOV2	Titles	2	0.360	0.478	0.622
Uni+O234+U2	GOV2	Titles	3	0.294	0.442	0.517
Uni+O234+U2	GOV2	Titles	4	0.290	0.454	0.545
Uni+O234+U2	GOV2	Titles	Joint	0.325	0.446	0.555
Uni+O234+U2	GOV2	Titles	Avg.	0.328	0.449	0.557
Uni+O234+U2	GOV2	Titles	Oracle	0.328	0.450	0.558
Uni+O234+U2	GOV2	Desc.	0	0.241	0.414	0.464
Uni+O234+U2	GOV2	Desc.	1	0.297	0.419	0.540
Uni+O234+U2	GOV2	Desc.	2	0.288	0.428	0.475
Uni+O234+U2	GOV2	Desc.	3	0.332	0.439	0.622
Uni+O234+U2	GOV2	Desc.	4	0.257	0.343	0.477
Uni+O234+U2	GOV2	Desc.	Joint	0.283	0.409	0.516
Uni+O234+U2	GOV2	Desc.	Avg.	0.284	0.410	0.515
Uni+O234+U2	GOV2	Desc.	Oracle	0.284	0.412	0.516
Uni+O234+U2	ClueWeb-09-B	Titles	0	0.129	0.280	0.428
Uni+O234+U2	ClueWeb-09-B	Titles	1	0.108	0.218	0.337
Uni+O234+U2	ClueWeb-09-B	Titles	2	0.128	0.326	0.422
Uni+O234+U2	ClueWeb-09-B	Titles	3	0.100	0.255	0.326
Uni+O234+U2	ClueWeb-09-B	Titles	4	0.078	0.138	0.238
Uni+O234+U2	ClueWeb-09-B	Titles	Joint	0.109	0.243	0.350
Uni+O234+U2	ClueWeb-09-B	Titles	Avg.	0.112	0.248	0.353
Uni+O234+U2	ClueWeb-09-B	Titles	Oracle	0.112	0.247	0.351
Uni+O234+U2	ClueWeb-09-B	Desc.	0	0.049	0.148	0.212
Uni+O234+U2	ClueWeb-09-B	Desc.	1	0.088	0.216	0.253
Uni+O234+U2	ClueWeb-09-B	Desc.	2	0.105	0.228	0.279
Uni+O234+U2	ClueWeb-09-B	Desc.	3	0.106	0.265	0.357
Uni+O234+U2	ClueWeb-09-B	Desc.	4	0.050	0.153	0.179
Uni+O234+U2	ClueWeb-09-B	Desc.	Joint	0.079	0.202	0.256
Uni+O234+U2	ClueWeb-09-B	Desc.	Avg.	0.082	0.201	0.255
Uni+O234+U2	ClueWeb-09-B	Desc.	Oracle	0.082	0.203	0.256
Uni+O23+U23	Robust-04	Titles	0	0.276	0.415	0.369
Uni+O23+U23	Robust-04	Titles	1	0.269	0.417	0.365
Uni+O23+U23	Robust-04	Titles	2	0.267	0.461	0.416
Uni+O23+U23	Robust-04	Titles	3	0.262	0.430	0.369
Uni+O23+U23	Robust-04	Titles	4	0.242	0.399	0.357
Uni+O23+U23	Robust-04	Titles	Joint	0.263	0.424	0.375
Uni+O23+U23	Robust-04	Titles	Avg.	0.265	0.426	0.377
Uni+O23+U23	Robust-04	Titles	Oracle	0.265	0.427	0.379
Uni+O23+U23	Robust-04	Desc.	0	0.277	0.418	0.354
Uni+O23+U23	Robust-04	Desc.	1	0.270	0.424	0.357
Uni+O23+U23	Robust-04	Desc.	2	0.258	0.404	0.342
Uni+O23+U23	Robust-04	Desc.	3	0.244	0.404	0.382
Uni+O23+U23	Robust-04	Desc.	4	0.249	0.398	0.315
Uni+O23+U23	Robust-04	Desc.	Joint	0.260	0.410	0.350
Uni+O23+U23	Robust-04	Desc.	Avg.	0.261	0.412	0.352
Uni+O23+U23	Robust-04	Desc.	Oracle	0.261	0.410	0.352
Uni+O23+U23	GOV2	Titles	0	0.322	0.423	0.507

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
Uni+O23+U23	GOV2	Titles	1	0.357	0.431	0.580
Uni+O23+U23	GOV2	Titles	2	0.358	0.467	0.607
Uni+O23+U23	GOV2	Titles	3	0.296	0.451	0.530
Uni+O23+U23	GOV2	Titles	4	0.295	0.455	0.545
Uni+O23+U23	GOV2	Titles	Joint	0.325	0.445	0.553
Uni+O23+U23	GOV2	Titles	Avg.	0.329	0.448	0.555
Uni+O23+U23	GOV2	Titles	Oracle	0.327	0.449	0.555
Uni+O23+U23	GOV2	Desc.	0	0.238	0.401	0.453
Uni+O23+U23	GOV2	Desc.	1	0.292	0.412	0.528
Uni+O23+U23	GOV2	Desc.	2	0.287	0.430	0.487
Uni+O23+U23	GOV2	Desc.	3	0.332	0.444	0.628
Uni+O23+U23	GOV2	Desc.	4	0.255	0.356	0.483
Uni+O23+U23	GOV2	Desc.	Joint	0.281	0.409	0.516
Uni+O23+U23	GOV2	Desc.	Avg.	0.285	0.412	0.519
Uni+O23+U23	GOV2	Desc.	Oracle	0.283	0.410	0.513
Uni+O23+U23	ClueWeb-09-B	Titles	0	0.130	0.279	0.429
Uni+O23+U23	ClueWeb-09-B	Titles	1	0.107	0.215	0.333
Uni+O23+U23	ClueWeb-09-B	Titles	2	0.127	0.330	0.430
Uni+O23+U23	ClueWeb-09-B	Titles	3	0.099	0.255	0.324
Uni+O23+U23	ClueWeb-09-B	Titles	4	0.077	0.136	0.232
Uni+O23+U23	ClueWeb-09-B	Titles	Joint	0.108	0.243	0.349
Uni+O23+U23	ClueWeb-09-B	Titles	Avg.	0.112	0.252	0.355
Uni+O23+U23	ClueWeb-09-B	Titles	Oracle	0.112	0.251	0.352
Uni+O23+U23	ClueWeb-09-B	Desc.	0	0.052	0.156	0.228
Uni+O23+U23	ClueWeb-09-B	Desc.	1	0.081	0.208	0.243
Uni+O23+U23	ClueWeb-09-B	Desc.	2	0.094	0.221	0.283
Uni+O23+U23	ClueWeb-09-B	Desc.	3	0.106	0.262	0.343
Uni+O23+U23	ClueWeb-09-B	Desc.	4	0.045	0.129	0.162
Uni+O23+U23	ClueWeb-09-B	Desc.	Joint	0.076	0.196	0.252
Uni+O23+U23	ClueWeb-09-B	Desc.	Avg.	0.081	0.201	0.250
Uni+O23+U23	ClueWeb-09-B	Desc.	Oracle	0.078	0.199	0.255
Uni+O234+U234	Robust-04	Desc.	0	0.277	0.419	0.355
Uni+O234+U234	Robust-04	Desc.	1	0.267	0.420	0.360
Uni+O234+U234	Robust-04	Desc.	2	0.259	0.398	0.338
Uni+O234+U234	Robust-04	Desc.	3	0.244	0.408	0.387
Uni+O234+U234	Robust-04	Desc.	4	0.249	0.402	0.324
Uni+O234+U234	Robust-04	Desc.	Joint	0.259	0.409	0.353
Uni+O234+U234	Robust-04	Desc.	Avg.	0.261	0.412	0.353
Uni+O234+U234	Robust-04	Desc.	Oracle	0.260	0.411	0.352
Uni+O234+U234	GOV2	Desc.	0	0.240	0.410	0.460
Uni+O234+U234	GOV2	Desc.	1	0.293	0.422	0.540
Uni+O234+U234	GOV2	Desc.	2	0.283	0.424	0.467
Uni+O234+U234	GOV2	Desc.	3	0.333	0.447	0.623
Uni+O234+U234	GOV2	Desc.	4	0.256	0.348	0.463
Uni+O234+U234	GOV2	Desc.	Joint	0.282	0.410	0.511
Uni+O234+U234	GOV2	Desc.	Avg.	0.285	0.411	0.518
Uni+O234+U234	GOV2	Desc.	Oracle	0.284	0.406	0.518
Uni+O234+U234	ClueWeb-09-B	Desc.	0	0.051	0.157	0.225
Uni+O234+U234	ClueWeb-09-B	Desc.	1	0.086	0.206	0.232
Uni+O234+U234	ClueWeb-09-B	Desc.	2	0.105	0.225	0.264
Uni+O234+U234	ClueWeb-09-B	Desc.	3	0.106	0.259	0.357
Uni+O234+U234	ClueWeb-09-B	Desc.	4	0.049	0.148	0.184

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
Uni+O234+U234	ClueWeb-09-B	Desc.	Joint	0.079	0.199	0.253
Uni+O234+U234	ClueWeb-09-B	Desc.	Avg.	0.082	0.203	0.254
Uni+O234+U234	ClueWeb-09-B	Desc.	Oracle	0.076	0.198	0.257
WSDM	Robust-04	Titles	0	0.292	0.427	0.377
WSDM	Robust-04	Titles	1	0.275	0.428	0.368
WSDM	Robust-04	Titles	2	0.277	0.470	0.428
WSDM	Robust-04	Titles	3	0.269	0.442	0.382
WSDM	Robust-04	Titles	4	0.244	0.406	0.363
WSDM	Robust-04	Titles	Joint	0.271	0.435	0.383
WSDM	Robust-04	Titles	Avg.	0.272	0.435	0.383
WSDM	Robust-04	Titles	Oracle	0.272	0.436	0.384
WSDM	Robust-04	Desc.	0	0.297	0.429	0.362
WSDM	Robust-04	Desc.	1	0.289	0.433	0.365
WSDM	Robust-04	Desc.	2	0.286	0.438	0.358
WSDM	Robust-04	Desc.	3	0.263	0.426	0.401
WSDM	Robust-04	Desc.	4	0.278	0.431	0.342
WSDM	Robust-04	Desc.	Joint	0.283	0.431	0.366
WSDM	Robust-04	Desc.	Avg.	0.283	0.434	0.370
WSDM	Robust-04	Desc.	Oracle	0.284	0.433	0.368
WSDM	GOV2	Titles	0	0.331	0.419	0.497
WSDM	GOV2	Titles	1	0.358	0.438	0.592
WSDM	GOV2	Titles	2	0.365	0.482	0.641
WSDM	GOV2	Titles	3	0.295	0.451	0.527
WSDM	GOV2	Titles	4	0.307	0.476	0.563
WSDM	GOV2	Titles	Joint	0.331	0.453	0.563
WSDM	GOV2	Titles	Avg.	0.333	0.456	0.565
WSDM	GOV2	Titles	Oracle	0.333	0.453	0.562
WSDM	GOV2	Desc.	0	0.277	0.441	0.519
WSDM	GOV2	Desc.	1	0.331	0.439	0.555
WSDM	GOV2	Desc.	2	0.303	0.459	0.497
WSDM	GOV2	Desc.	3	0.352	0.456	0.653
WSDM	GOV2	Desc.	4	0.253	0.334	0.457
WSDM	GOV2	Desc.	Joint	0.303	0.426	0.536
WSDM	GOV2	Desc.	Avg.	0.308	0.431	0.540
WSDM	GOV2	Desc.	Oracle	0.305	0.439	0.544
WSDM	ClueWeb-09-B	Titles	0	0.129	0.265	0.416
WSDM	ClueWeb-09-B	Titles	1	0.116	0.230	0.352
WSDM	ClueWeb-09-B	Titles	2	0.134	0.327	0.418
WSDM	ClueWeb-09-B	Titles	3	0.102	0.255	0.331
WSDM	ClueWeb-09-B	Titles	4	0.077	0.143	0.243
WSDM	ClueWeb-09-B	Titles	Joint	0.111	0.244	0.352
WSDM	ClueWeb-09-B	Titles	Avg.	0.114	0.251	0.359
WSDM	ClueWeb-09-B	Titles	Oracle	0.114	0.250	0.360
WSDM	ClueWeb-09-B	Desc.	0	0.062	0.182	0.257
WSDM	ClueWeb-09-B	Desc.	1	0.092	0.235	0.270
WSDM	ClueWeb-09-B	Desc.	2	0.119	0.235	0.274
WSDM	ClueWeb-09-B	Desc.	3	0.111	0.279	0.388
WSDM	ClueWeb-09-B	Desc.	4	0.057	0.161	0.222
WSDM	ClueWeb-09-B	Desc.	Joint	0.088	0.219	0.283
WSDM	ClueWeb-09-B	Desc.	Avg.	0.089	0.218	0.287
WSDM	ClueWeb-09-B	Desc.	Oracle	0.088	0.220	0.284
WSDM-Int	Robust-04	Titles	0	0.288	0.427	0.379

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
WSDM-Int	Robust-04	Titles	1	0.274	0.428	0.368
WSDM-Int	Robust-04	Titles	2	0.278	0.473	0.432
WSDM-Int	Robust-04	Titles	3	0.265	0.436	0.373
WSDM-Int	Robust-04	Titles	4	0.241	0.396	0.356
WSDM-Int	Robust-04	Titles	Joint	0.269	0.432	0.382
WSDM-Int	Robust-04	Titles	Avg.	0.272	0.434	0.382
WSDM-Int	Robust-04	Titles	Oracle	0.272	0.436	0.384
WSDM-Int	Robust-04	Desc.	0	0.294	0.431	0.361
WSDM-Int	Robust-04	Desc.	1	0.286	0.429	0.363
WSDM-Int	Robust-04	Desc.	2	0.276	0.431	0.359
WSDM-Int	Robust-04	Desc.	3	0.259	0.417	0.391
WSDM-Int	Robust-04	Desc.	4	0.274	0.430	0.350
WSDM-Int	Robust-04	Desc.	Joint	0.278	0.428	0.365
WSDM-Int	Robust-04	Desc.	Avg.	0.281	0.430	0.365
WSDM-Int	Robust-04	Desc.	Oracle	0.281	0.431	0.367
WSDM-Int	GOV2	Titles	0	0.330	0.418	0.487
WSDM-Int	GOV2	Titles	1	0.355	0.435	0.593
WSDM-Int	GOV2	Titles	2	0.363	0.481	0.636
WSDM-Int	GOV2	Titles	3	0.292	0.443	0.517
WSDM-Int	GOV2	Titles	4	0.306	0.473	0.552
WSDM-Int	GOV2	Titles	Joint	0.329	0.450	0.556
WSDM-Int	GOV2	Titles	Avg.	0.333	0.455	0.563
WSDM-Int	GOV2	Titles	Oracle	0.333	0.455	0.563
WSDM-Int	GOV2	Desc.	0	0.270	0.448	0.524
WSDM-Int	GOV2	Desc.	1	0.321	0.431	0.545
WSDM-Int	GOV2	Desc.	2	0.294	0.455	0.488
WSDM-Int	GOV2	Desc.	3	0.347	0.452	0.648
WSDM-Int	GOV2	Desc.	4	0.257	0.341	0.458
WSDM-Int	GOV2	Desc.	Joint	0.298	0.425	0.533
WSDM-Int	GOV2	Desc.	Avg.	0.301	0.428	0.536
WSDM-Int	GOV2	Desc.	Oracle	0.300	0.423	0.534
WSDM-Int	ClueWeb-09-B	Titles	0	0.129	0.264	0.417
WSDM-Int	ClueWeb-09-B	Titles	1	0.116	0.230	0.352
WSDM-Int	ClueWeb-09-B	Titles	2	0.140	0.335	0.430
WSDM-Int	ClueWeb-09-B	Titles	3	0.102	0.258	0.329
WSDM-Int	ClueWeb-09-B	Titles	4	0.075	0.139	0.245
WSDM-Int	ClueWeb-09-B	Titles	Joint	0.113	0.245	0.354
WSDM-Int	ClueWeb-09-B	Titles	Avg.	0.114	0.250	0.360
WSDM-Int	ClueWeb-09-B	Titles	Oracle	0.114	0.248	0.357
WSDM-Int	ClueWeb-09-B	Desc.	0	0.053	0.147	0.220
WSDM-Int	ClueWeb-09-B	Desc.	1	0.089	0.214	0.255
WSDM-Int	ClueWeb-09-B	Desc.	2	0.110	0.216	0.236
WSDM-Int	ClueWeb-09-B	Desc.	3	0.107	0.263	0.367
WSDM-Int	ClueWeb-09-B	Desc.	4	0.053	0.152	0.195
WSDM-Int	ClueWeb-09-B	Desc.	Joint	0.083	0.199	0.255
WSDM-Int	ClueWeb-09-B	Desc.	Avg.	0.086	0.209	0.270
WSDM-Int	ClueWeb-09-B	Desc.	Oracle	0.086	0.211	0.271
WSDM-Int-3	Robust-04	Titles	0	0.291	0.434	0.382
WSDM-Int-3	Robust-04	Titles	1	0.274	0.426	0.365
WSDM-Int-3	Robust-04	Titles	2	0.279	0.472	0.430
WSDM-Int-3	Robust-04	Titles	3	0.269	0.448	0.386
WSDM-Int-3	Robust-04	Titles	4	0.243	0.404	0.362

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
WSDM-Int-3	Robust-04	Titles	Joint	0.271	0.437	0.385
WSDM-Int-3	Robust-04	Titles	Avg.	0.273	0.437	0.384
WSDM-Int-3	Robust-04	Titles	Oracle	0.273	0.437	0.385
WSDM-Int-3	Robust-04	Desc.	0	0.295	0.431	0.357
WSDM-Int-3	Robust-04	Desc.	1	0.287	0.435	0.374
WSDM-Int-3	Robust-04	Desc.	2	0.281	0.432	0.359
WSDM-Int-3	Robust-04	Desc.	3	0.261	0.419	0.392
WSDM-Int-3	Robust-04	Desc.	4	0.275	0.424	0.338
WSDM-Int-3	Robust-04	Desc.	Joint	0.280	0.428	0.364
WSDM-Int-3	Robust-04	Desc.	Avg.	0.282	0.430	0.365
WSDM-Int-3	Robust-04	Desc.	Oracle	0.282	0.431	0.366
WSDM-Int-3	GOV2	Titles	0	0.334	0.419	0.490
WSDM-Int-3	GOV2	Titles	1	0.358	0.436	0.588
WSDM-Int-3	GOV2	Titles	2	0.362	0.480	0.645
WSDM-Int-3	GOV2	Titles	3	0.293	0.441	0.508
WSDM-Int-3	GOV2	Titles	4	0.304	0.468	0.550
WSDM-Int-3	GOV2	Titles	Joint	0.330	0.448	0.556
WSDM-Int-3	GOV2	Titles	Avg.	0.333	0.456	0.563
WSDM-Int-3	GOV2	Titles	Oracle	0.334	0.455	0.560
WSDM-Int-3	GOV2	Desc.	0	0.270	0.448	0.521
WSDM-Int-3	GOV2	Desc.	1	0.321	0.430	0.545
WSDM-Int-3	GOV2	Desc.	2	0.295	0.453	0.483
WSDM-Int-3	GOV2	Desc.	3	0.343	0.452	0.650
WSDM-Int-3	GOV2	Desc.	4	0.256	0.341	0.457
WSDM-Int-3	GOV2	Desc.	Joint	0.297	0.425	0.531
WSDM-Int-3	GOV2	Desc.	Avg.	0.301	0.427	0.534
WSDM-Int-3	GOV2	Desc.	Oracle	0.302	0.427	0.535
WSDM-Int-3	ClueWeb-09-B	Titles	0	0.130	0.266	0.414
WSDM-Int-3	ClueWeb-09-B	Titles	1	0.108	0.208	0.317
WSDM-Int-3	ClueWeb-09-B	Titles	2	0.137	0.337	0.432
WSDM-Int-3	ClueWeb-09-B	Titles	3	0.099	0.254	0.326
WSDM-Int-3	ClueWeb-09-B	Titles	4	0.081	0.149	0.247
WSDM-Int-3	ClueWeb-09-B	Titles	Joint	0.111	0.242	0.347
WSDM-Int-3	ClueWeb-09-B	Titles	Avg.	0.114	0.250	0.360
WSDM-Int-3	ClueWeb-09-B	Titles	Oracle	0.114	0.246	0.353
WSDM-Int-3	ClueWeb-09-B	Desc.	0	0.055	0.163	0.212
WSDM-Int-3	ClueWeb-09-B	Desc.	1	0.083	0.213	0.248
WSDM-Int-3	ClueWeb-09-B	Desc.	2	0.103	0.215	0.245
WSDM-Int-3	ClueWeb-09-B	Desc.	3	0.105	0.265	0.367
WSDM-Int-3	ClueWeb-09-B	Desc.	4	0.053	0.154	0.184
WSDM-Int-3	ClueWeb-09-B	Desc.	Joint	0.080	0.202	0.252
WSDM-Int-3	ClueWeb-09-B	Desc.	Avg.	0.086	0.210	0.262
WSDM-Int-3	ClueWeb-09-B	Desc.	Oracle	0.086	0.212	0.267
PLM	Robust-04	Titles	0	0.256	0.393	0.353
PLM	Robust-04	Titles	1	0.261	0.409	0.348
PLM	Robust-04	Titles	2	0.257	0.440	0.403
PLM	Robust-04	Titles	3	0.252	0.418	0.365
PLM	Robust-04	Titles	4	0.234	0.393	0.352
PLM	Robust-04	Titles	Joint	0.252	0.411	0.364
PLM	Robust-04	Titles	Avg.	0.253	0.412	0.365
PLM	Robust-04	Titles	Oracle	0.254	0.412	0.365
PLM	Robust-04	Desc.	0	0.269	0.389	0.328

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
PLM	Robust-04	Desc.	1	0.253	0.382	0.322
PLM	Robust-04	Desc.	2	0.248	0.385	0.344
PLM	Robust-04	Desc.	3	0.235	0.395	0.364
PLM	Robust-04	Desc.	4	0.244	0.382	0.300
PLM	Robust-04	Desc.	Joint	0.250	0.386	0.332
PLM	Robust-04	Desc.	Avg.	0.251	0.387	0.332
PLM	Robust-04	Desc.	Oracle	0.251	0.387	0.332
PLM	GOV2	Titles	Joint	0.305	0.406	0.509
PLM	GOV2	Desc.	Joint	0.247	0.337	0.433
PLM	ClueWeb-09-B	Titles	Joint	0.092	0.207	0.301
PLM	ClueWeb-09-B	Desc.	Joint	0.064	0.153	0.198
PLM-2	Robust-04	Titles	0	0.264	0.396	0.352
PLM-2	Robust-04	Titles	1	0.263	0.407	0.352
PLM-2	Robust-04	Titles	2	0.264	0.451	0.406
PLM-2	Robust-04	Titles	3	0.256	0.418	0.368
PLM-2	Robust-04	Titles	4	0.234	0.398	0.361
PLM-2	Robust-04	Titles	Joint	0.256	0.414	0.368
PLM-2	Robust-04	Titles	Avg.	0.248	0.409	0.359
PLM-2	Robust-04	Titles	Oracle	0.257	0.415	0.367
PLM-2	Robust-04	Desc.	0	0.282	0.413	0.348
PLM-2	Robust-04	Desc.	1	0.265	0.404	0.343
PLM-2	Robust-04	Desc.	2	0.254	0.385	0.339
PLM-2	Robust-04	Desc.	3	0.241	0.394	0.378
PLM-2	Robust-04	Desc.	4	0.255	0.395	0.318
PLM-2	Robust-04	Desc.	Joint	0.260	0.398	0.345
PLM-2	Robust-04	Desc.	Avg.	0.256	0.395	0.344
PLM-2	Robust-04	Desc.	Oracle	0.259	0.398	0.346
PLM-2	GOV2	Titles	Avg. †	0.302	0.410	0.506
PLM-2	GOV2	Desc.	Avg. †	0.276	0.390	0.485
PLM-2	ClueWeb-09-B	Titles	Avg. †	0.097	0.214	0.306
PLM-2	ClueWeb-09-B	Desc.	Avg. †	0.075	0.190	0.239
PL2	Robust-04	Titles	0	0.263	0.405	0.362
PL2	Robust-04	Titles	1	0.263	0.413	0.349
PL2	Robust-04	Titles	2	0.258	0.452	0.403
PL2	Robust-04	Titles	3	0.252	0.419	0.367
PL2	Robust-04	Titles	4	0.230	0.402	0.363
PL2	Robust-04	Titles	Joint	0.253	0.418	0.369
PL2	Robust-04	Titles	Avg.	0.253	0.418	0.368
PL2	Robust-04	Titles	Oracle	0.253	0.418	0.369
PL2	Robust-04	Desc.	0	0.247	0.392	0.327
PL2	Robust-04	Desc.	1	0.245	0.390	0.330
PL2	Robust-04	Desc.	2	0.228	0.398	0.333
PL2	Robust-04	Desc.	3	0.210	0.396	0.359
PL2	Robust-04	Desc.	4	0.217	0.367	0.296
PL2	Robust-04	Desc.	Joint	0.229	0.389	0.329
PL2	Robust-04	Desc.	Avg.	0.230	0.388	0.328
PL2	Robust-04	Desc.	Oracle	0.230	0.389	0.329
PL2	GOV2	Titles	0	0.302	0.413	0.507
PL2	GOV2	Titles	1	0.337	0.423	0.547
PL2	GOV2	Titles	2	0.341	0.423	0.559
PL2	GOV2	Titles	3	0.261	0.398	0.467
PL2	GOV2	Titles	4	0.258	0.417	0.503

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
PL2	GOV2	Titles	Joint	0.300	0.415	0.516
PL2	GOV2	Titles	Avg.	0.300	0.415	0.516
PL2	GOV2	Titles	Oracle	0.301	0.415	0.517
PL2	GOV2	Desc.	0	0.208	0.364	0.409
PL2	GOV2	Desc.	1	0.251	0.402	0.497
PL2	GOV2	Desc.	2	0.262	0.426	0.437
PL2	GOV2	Desc.	3	0.325	0.432	0.615
PL2	GOV2	Desc.	4	0.244	0.324	0.435
PL2	GOV2	Desc.	Joint	0.258	0.390	0.479
PL2	GOV2	Desc.	Avg.	0.259	0.391	0.478
PL2	GOV2	Desc.	Oracle	0.259	0.391	0.478
PL2	ClueWeb-09-B	Titles	0	0.123	0.238	0.397
PL2	ClueWeb-09-B	Titles	1	0.110	0.211	0.328
PL2	ClueWeb-09-B	Titles	2	0.128	0.330	0.425
PL2	ClueWeb-09-B	Titles	3	0.094	0.249	0.310
PL2	ClueWeb-09-B	Titles	4	0.070	0.136	0.228
PL2	ClueWeb-09-B	Titles	Joint	0.105	0.233	0.337
PL2	ClueWeb-09-B	Titles	Avg.	0.105	0.233	0.337
PL2	ClueWeb-09-B	Titles	Oracle	0.105	0.233	0.337
PL2	ClueWeb-09-B	Desc.	0	0.049	0.150	0.198
PL2	ClueWeb-09-B	Desc.	1	0.076	0.192	0.223
PL2	ClueWeb-09-B	Desc.	2	0.107	0.221	0.260
PL2	ClueWeb-09-B	Desc.	3	0.106	0.257	0.358
PL2	ClueWeb-09-B	Desc.	4	0.046	0.148	0.193
PL2	ClueWeb-09-B	Desc.	Joint	0.077	0.194	0.247
PL2	ClueWeb-09-B	Desc.	Avg.	0.078	0.194	0.249
PL2	ClueWeb-09-B	Desc.	Oracle	0.078	0.193	0.247
pDFR-BiL2	Robust-04	Titles	0	0.267	0.402	0.363
pDFR-BiL2	Robust-04	Titles	1	0.271	0.422	0.366
pDFR-BiL2	Robust-04	Titles	2	0.262	0.459	0.409
pDFR-BiL2	Robust-04	Titles	3	0.255	0.418	0.358
pDFR-BiL2	Robust-04	Titles	4	0.237	0.409	0.365
pDFR-BiL2	Robust-04	Titles	Joint	0.258	0.422	0.372
pDFR-BiL2	Robust-04	Titles	Avg.	0.259	0.422	0.372
pDFR-BiL2	Robust-04	Titles	Oracle	0.260	0.424	0.374
pDFR-BiL2	Robust-04	Desc.	0	0.255	0.402	0.335
pDFR-BiL2	Robust-04	Desc.	1	0.251	0.405	0.343
pDFR-BiL2	Robust-04	Desc.	2	0.234	0.394	0.330
pDFR-BiL2	Robust-04	Desc.	3	0.207	0.388	0.361
pDFR-BiL2	Robust-04	Desc.	4	0.222	0.378	0.306
pDFR-BiL2	Robust-04	Desc.	Joint	0.234	0.393	0.335
pDFR-BiL2	Robust-04	Desc.	Avg.	0.235	0.394	0.335
pDFR-BiL2	Robust-04	Desc.	Oracle	0.236	0.397	0.336
pDFR-BiL2	GOV2	Titles	0	0.320	0.434	0.533
pDFR-BiL2	GOV2	Titles	1	0.353	0.447	0.580
pDFR-BiL2	GOV2	Titles	2	0.349	0.463	0.600
pDFR-BiL2	GOV2	Titles	3	0.277	0.411	0.473
pDFR-BiL2	GOV2	Titles	4	0.267	0.430	0.495
pDFR-BiL2	GOV2	Titles	Joint	0.313	0.437	0.536
pDFR-BiL2	GOV2	Titles	Avg.	0.314	0.436	0.536
pDFR-BiL2	GOV2	Titles	Oracle	0.314	0.436	0.536
pDFR-BiL2	GOV2	Desc.	0	0.217	0.363	0.410

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
pDFR-BiL2	GOV2	Desc.	1	0.255	0.399	0.495
pDFR-BiL2	GOV2	Desc.	2	0.269	0.445	0.467
pDFR-BiL2	GOV2	Desc.	3	0.334	0.437	0.623
pDFR-BiL2	GOV2	Desc.	4	0.252	0.325	0.433
pDFR-BiL2	GOV2	Desc.	Joint	0.266	0.394	0.486
pDFR-BiL2	GOV2	Desc.	Avg.	0.267	0.394	0.484
pDFR-BiL2	GOV2	Desc.	Oracle	0.267	0.395	0.484
pDFR-BiL2	ClueWeb-09-B	Titles	0	0.124	0.232	0.384
pDFR-BiL2	ClueWeb-09-B	Titles	1	0.100	0.189	0.298
pDFR-BiL2	ClueWeb-09-B	Titles	2	0.124	0.318	0.407
pDFR-BiL2	ClueWeb-09-B	Titles	3	0.093	0.254	0.314
pDFR-BiL2	ClueWeb-09-B	Titles	4	0.070	0.135	0.228
pDFR-BiL2	ClueWeb-09-B	Titles	Joint	0.102	0.225	0.326
pDFR-BiL2	ClueWeb-09-B	Titles	Avg.	0.105	0.232	0.339
pDFR-BiL2	ClueWeb-09-B	Titles	Oracle	0.106	0.230	0.330
pDFR-BiL2	ClueWeb-09-B	Desc.	0	0.048	0.151	0.200
pDFR-BiL2	ClueWeb-09-B	Desc.	1	0.076	0.190	0.222
pDFR-BiL2	ClueWeb-09-B	Desc.	2	0.106	0.214	0.248
pDFR-BiL2	ClueWeb-09-B	Desc.	3	0.104	0.252	0.355
pDFR-BiL2	ClueWeb-09-B	Desc.	4	0.046	0.150	0.197
pDFR-BiL2	ClueWeb-09-B	Desc.	Joint	0.076	0.192	0.245
pDFR-BiL2	ClueWeb-09-B	Desc.	Avg.	0.078	0.194	0.247
pDFR-BiL2	ClueWeb-09-B	Desc.	Oracle	0.078	0.193	0.247
pDFR-PL2	Robust-04	Titles	0	0.274	0.406	0.365
pDFR-PL2	Robust-04	Titles	1	0.270	0.424	0.365
pDFR-PL2	Robust-04	Titles	2	0.259	0.450	0.411
pDFR-PL2	Robust-04	Titles	3	0.258	0.423	0.364
pDFR-PL2	Robust-04	Titles	4	0.238	0.408	0.370
pDFR-PL2	Robust-04	Titles	Joint	0.260	0.422	0.375
pDFR-PL2	Robust-04	Titles	Avg.	0.261	0.423	0.376
pDFR-PL2	Robust-04	Titles	Oracle	0.261	0.423	0.376
pDFR-PL2	Robust-04	Desc.	0	0.256	0.403	0.333
pDFR-PL2	Robust-04	Desc.	1	0.253	0.399	0.338
pDFR-PL2	Robust-04	Desc.	2	0.234	0.396	0.334
pDFR-PL2	Robust-04	Desc.	3	0.210	0.392	0.357
pDFR-PL2	Robust-04	Desc.	4	0.225	0.374	0.300
pDFR-PL2	Robust-04	Desc.	Joint	0.235	0.393	0.333
pDFR-PL2	Robust-04	Desc.	Avg.	0.237	0.396	0.337
pDFR-PL2	Robust-04	Desc.	Oracle	0.237	0.398	0.337
pDFR-PL2	GOV2	Titles	0	0.324	0.436	0.528
pDFR-PL2	GOV2	Titles	1	0.353	0.439	0.587
pDFR-PL2	GOV2	Titles	2	0.339	0.447	0.581
pDFR-PL2	GOV2	Titles	3	0.286	0.431	0.492
pDFR-PL2	GOV2	Titles	4	0.286	0.452	0.533
pDFR-PL2	GOV2	Titles	Joint	0.317	0.441	0.544
pDFR-PL2	GOV2	Titles	Avg.	0.321	0.442	0.547
pDFR-PL2	GOV2	Titles	Oracle	0.321	0.442	0.547
pDFR-PL2	GOV2	Desc.	0	0.218	0.374	0.414
pDFR-PL2	GOV2	Desc.	1	0.266	0.421	0.522
pDFR-PL2	GOV2	Desc.	2	0.274	0.432	0.452
pDFR-PL2	GOV2	Desc.	3	0.335	0.450	0.627
pDFR-PL2	GOV2	Desc.	4	0.258	0.337	0.452

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
pDFR-PL2	GOV2	Desc.	Joint	0.270	0.403	0.494
pDFR-PL2	GOV2	Desc.	Avg.	0.272	0.403	0.493
pDFR-PL2	GOV2	Desc.	Oracle	0.272	0.404	0.494
pDFR-PL2	ClueWeb-09-B	Titles	0	0.134	0.294	0.455
pDFR-PL2	ClueWeb-09-B	Titles	1	0.116	0.233	0.353
pDFR-PL2	ClueWeb-09-B	Titles	2	0.124	0.314	0.400
pDFR-PL2	ClueWeb-09-B	Titles	3	0.103	0.268	0.345
pDFR-PL2	ClueWeb-09-B	Titles	4	0.077	0.132	0.238
pDFR-PL2	ClueWeb-09-B	Titles	Joint	0.111	0.248	0.358
pDFR-PL2	ClueWeb-09-B	Titles	Avg.	0.113	0.256	0.368
pDFR-PL2	ClueWeb-09-B	Titles	Oracle	0.113	0.255	0.367
pDFR-PL2	ClueWeb-09-B	Desc.	0	0.050	0.137	0.195
pDFR-PL2	ClueWeb-09-B	Desc.	1	0.086	0.201	0.237
pDFR-PL2	ClueWeb-09-B	Desc.	2	0.110	0.228	0.257
pDFR-PL2	ClueWeb-09-B	Desc.	3	0.112	0.273	0.378
pDFR-PL2	ClueWeb-09-B	Desc.	4	0.044	0.123	0.148
pDFR-PL2	ClueWeb-09-B	Desc.	Joint	0.080	0.193	0.244
pDFR-PL2	ClueWeb-09-B	Desc.	Avg.	0.082	0.200	0.250
pDFR-PL2	ClueWeb-09-B	Desc.	Oracle	0.082	0.200	0.250
BM25	Robust-04	Titles	0	0.261	0.396	0.351
BM25	Robust-04	Titles	1	0.261	0.401	0.343
BM25	Robust-04	Titles	2	0.263	0.461	0.411
BM25	Robust-04	Titles	3	0.253	0.412	0.359
BM25	Robust-04	Titles	4	0.230	0.390	0.351
BM25	Robust-04	Titles	Joint	0.254	0.412	0.363
BM25	Robust-04	Titles	Avg.	0.254	0.412	0.363
BM25	Robust-04	Titles	Oracle	0.255	0.413	0.362
BM25	Robust-04	Desc.	0	0.255	0.410	0.340
BM25	Robust-04	Desc.	1	0.250	0.395	0.333
BM25	Robust-04	Desc.	2	0.238	0.397	0.335
BM25	Robust-04	Desc.	3	0.219	0.389	0.353
BM25	Robust-04	Desc.	4	0.221	0.361	0.291
BM25	Robust-04	Desc.	Joint	0.237	0.390	0.331
BM25	Robust-04	Desc.	Avg.	0.238	0.394	0.334
BM25	Robust-04	Desc.	Oracle	0.239	0.391	0.331
BM25	GOV2	Titles	0	0.299	0.407	0.488
BM25	GOV2	Titles	1	0.343	0.458	0.587
BM25	GOV2	Titles	2	0.340	0.454	0.593
BM25	GOV2	Titles	3	0.256	0.405	0.455
BM25	GOV2	Titles	4	0.260	0.453	0.528
BM25	GOV2	Titles	Joint	0.299	0.435	0.530
BM25	GOV2	Titles	Avg.	0.300	0.435	0.529
BM25	GOV2	Titles	Oracle	0.301	0.436	0.531
BM25	GOV2	Desc.	0	0.206	0.362	0.414
BM25	GOV2	Desc.	1	0.272	0.428	0.507
BM25	GOV2	Desc.	2	0.252	0.433	0.447
BM25	GOV2	Desc.	3	0.323	0.427	0.595
BM25	GOV2	Desc.	4	0.248	0.352	0.453
BM25	GOV2	Desc.	Joint	0.261	0.401	0.484
BM25	GOV2	Desc.	Avg.	0.261	0.402	0.484
BM25	GOV2	Desc.	Oracle	0.261	0.400	0.484
BM25	ClueWeb-09-B	Titles	0	0.118	0.226	0.381

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
BM25	ClueWeb-09-B	Titles	1	0.088	0.171	0.273
BM25	ClueWeb-09-B	Titles	2	0.124	0.324	0.405
BM25	ClueWeb-09-B	Titles	3	0.089	0.243	0.300
BM25	ClueWeb-09-B	Titles	4	0.077	0.154	0.262
BM25	ClueWeb-09-B	Titles	Joint	0.099	0.223	0.324
BM25	ClueWeb-09-B	Titles	Avg.	0.101	0.230	0.334
BM25	ClueWeb-09-B	Titles	Oracle	0.102	0.226	0.329
BM25	ClueWeb-09-B	Desc.	0	0.054	0.153	0.213
BM25	ClueWeb-09-B	Desc.	1	0.079	0.206	0.258
BM25	ClueWeb-09-B	Desc.	2	0.104	0.217	0.250
BM25	ClueWeb-09-B	Desc.	3	0.115	0.280	0.380
BM25	ClueWeb-09-B	Desc.	4	0.053	0.150	0.195
BM25	ClueWeb-09-B	Desc.	Joint	0.081	0.201	0.260
BM25	ClueWeb-09-B	Desc.	Avg.	0.082	0.203	0.262
BM25	ClueWeb-09-B	Desc.	Oracle	0.083	0.203	0.259
BM25-TP	Robust-04	Titles	0	0.275	0.407	0.369
BM25-TP	Robust-04	Titles	1	0.273	0.426	0.370
BM25-TP	Robust-04	Titles	2	0.266	0.454	0.408
BM25-TP	Robust-04	Titles	3	0.257	0.409	0.350
BM25-TP	Robust-04	Titles	4	0.239	0.394	0.358
BM25-TP	Robust-04	Titles	Joint	0.262	0.418	0.371
BM25-TP	Robust-04	Titles	Avg.	0.263	0.417	0.368
BM25-TP	Robust-04	Titles	Oracle	0.264	0.420	0.371
BM25-TP	Robust-04	Desc.	0	0.247	0.391	0.328
BM25-TP	Robust-04	Desc.	1	0.261	0.414	0.349
BM25-TP	Robust-04	Desc.	2	0.246	0.403	0.338
BM25-TP	Robust-04	Desc.	3	0.226	0.396	0.362
BM25-TP	Robust-04	Desc.	4	0.232	0.363	0.300
BM25-TP	Robust-04	Desc.	Joint	0.243	0.394	0.336
BM25-TP	Robust-04	Desc.	Avg.	0.244	0.395	0.337
BM25-TP	Robust-04	Desc.	Oracle	0.244	0.397	0.338
BM25-TP	GOV2	Titles	0	0.328	0.439	0.533
BM25-TP	GOV2	Titles	1	0.347	0.442	0.615
BM25-TP	GOV2	Titles	2	0.343	0.463	0.612
BM25-TP	GOV2	Titles	3	0.292	0.423	0.482
BM25-TP	GOV2	Titles	4	0.296	0.460	0.540
BM25-TP	GOV2	Titles	Joint	0.321	0.445	0.556
BM25-TP	GOV2	Titles	Avg.	0.322	0.446	0.558
BM25-TP	GOV2	Titles	Oracle	0.322	0.447	0.559
BM25-TP	GOV2	Desc.	0	0.223	0.410	0.469
BM25-TP	GOV2	Desc.	1	0.294	0.411	0.508
BM25-TP	GOV2	Desc.	2	0.276	0.435	0.480
BM25-TP	GOV2	Desc.	3	0.314	0.432	0.622
BM25-TP	GOV2	Desc.	4	0.249	0.346	0.468
BM25-TP	GOV2	Desc.	Joint	0.272	0.407	0.510
BM25-TP	GOV2	Desc.	Avg.	0.273	0.409	0.510
BM25-TP	GOV2	Desc.	Oracle	0.273	0.410	0.510
BM25-TP	ClueWeb-09-B	Titles	0	0.128	0.273	0.426
BM25-TP	ClueWeb-09-B	Titles	1	0.101	0.217	0.328
BM25-TP	ClueWeb-09-B	Titles	2	0.126	0.307	0.405
BM25-TP	ClueWeb-09-B	Titles	3	0.104	0.262	0.340
BM25-TP	ClueWeb-09-B	Titles	4	0.086	0.153	0.250

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
BM25-TP	ClueWeb-09-B	Titles	Joint	0.109	0.242	0.349
BM25-TP	ClueWeb-09-B	Titles	Avg.	0.110	0.250	0.359
BM25-TP	ClueWeb-09-B	Titles	Oracle	0.111	0.250	0.360
BM25-TP	ClueWeb-09-B	Desc.	0	0.056	0.143	0.208
BM25-TP	ClueWeb-09-B	Desc.	1	0.085	0.223	0.250
BM25-TP	ClueWeb-09-B	Desc.	2	0.117	0.246	0.284
BM25-TP	ClueWeb-09-B	Desc.	3	0.115	0.265	0.367
BM25-TP	ClueWeb-09-B	Desc.	4	0.050	0.125	0.178
BM25-TP	ClueWeb-09-B	Desc.	Joint	0.084	0.201	0.258
BM25-TP	ClueWeb-09-B	Desc.	Avg.	0.086	0.204	0.260
BM25-TP	ClueWeb-09-B	Desc.	Oracle	0.086	0.204	0.260
BM25-TP2	Robust-04	Titles	0	0.266	0.390	0.339
BM25-TP2	Robust-04	Titles	1	0.266	0.425	0.359
BM25-TP2	Robust-04	Titles	2	0.241	0.415	0.370
BM25-TP2	Robust-04	Titles	3	0.244	0.377	0.332
BM25-TP2	Robust-04	Titles	4	0.223	0.374	0.338
BM25-TP2	Robust-04	Titles	Joint	0.248	0.396	0.348
BM25-TP2	Robust-04	Titles	Avg.	0.250	0.399	0.350
BM25-TP2	Robust-04	Titles	Oracle	0.250	0.399	0.350
BM25-TP2	Robust-04	Desc.	0	0.203	0.324	0.254
BM25-TP2	Robust-04	Desc.	1	0.239	0.389	0.321
BM25-TP2	Robust-04	Desc.	2	0.222	0.359	0.290
BM25-TP2	Robust-04	Desc.	3	0.203	0.358	0.335
BM25-TP2	Robust-04	Desc.	4	0.206	0.349	0.312
BM25-TP2	Robust-04	Desc.	Joint	0.215	0.356	0.302
BM25-TP2	Robust-04	Desc.	Avg.	0.216	0.358	0.303
BM25-TP2	Robust-04	Desc.	Oracle	0.216	0.359	0.305
BM25-TP2	GOV2	Titles	0	0.294	0.381	0.440
BM25-TP2	GOV2	Titles	1	0.262	0.332	0.477
BM25-TP2	GOV2	Titles	2	0.305	0.399	0.526
BM25-TP2	GOV2	Titles	3	0.261	0.395	0.478
BM25-TP2	GOV2	Titles	4	0.243	0.404	0.478
BM25-TP2	GOV2	Titles	Joint	0.273	0.382	0.480
BM25-TP2	GOV2	Titles	Avg.	0.275	0.384	0.484
BM25-TP2	GOV2	Titles	Oracle	0.275	0.387	0.488
BM25-TP2	GOV2	Desc.	0	0.187	0.349	0.378
BM25-TP2	GOV2	Desc.	1	0.244	0.403	0.488
BM25-TP2	GOV2	Desc.	2	0.233	0.381	0.412
BM25-TP2	GOV2	Desc.	3	0.285	0.417	0.597
BM25-TP2	GOV2	Desc.	4	0.183	0.249	0.357
BM25-TP2	GOV2	Desc.	Joint	0.227	0.360	0.447
BM25-TP2	GOV2	Desc.	Avg.	0.229	0.358	0.448
BM25-TP2	GOV2	Desc.	Oracle	0.229	0.361	0.451
BM25-TP2	ClueWeb-09-B	Titles	0	0.114	0.266	0.409
BM25-TP2	ClueWeb-09-B	Titles	1	0.092	0.219	0.305
BM25-TP2	ClueWeb-09-B	Titles	2	0.124	0.304	0.408
BM25-TP2	ClueWeb-09-B	Titles	3	0.097	0.254	0.328
BM25-TP2	ClueWeb-09-B	Titles	4	0.076	0.145	0.210
BM25-TP2	ClueWeb-09-B	Titles	Joint	0.100	0.237	0.331
BM25-TP2	ClueWeb-09-B	Titles	Avg.	0.102	0.239	0.333
BM25-TP2	ClueWeb-09-B	Titles	Oracle	0.102	0.239	0.331
BM25-TP2	ClueWeb-09-B	Desc.	0	0.050	0.120	0.168

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
BM25-TP2	ClueWeb-09-B	Desc.	1	0.071	0.198	0.223
BM25-TP2	ClueWeb-09-B	Desc.	2	0.084	0.206	0.250
BM25-TP2	ClueWeb-09-B	Desc.	3	0.108	0.267	0.357
BM25-TP2	ClueWeb-09-B	Desc.	4	0.049	0.115	0.157
BM25-TP2	ClueWeb-09-B	Desc.	Joint	0.073	0.182	0.231
BM25-TP2	ClueWeb-09-B	Desc.	Avg.	0.074	0.185	0.236
BM25-TP2	ClueWeb-09-B	Desc.	Oracle	0.075	0.186	0.239
BM25-Span	Robust-04	Titles	0	0.271	0.402	0.357
BM25-Span	Robust-04	Titles	1	0.271	0.419	0.361
BM25-Span	Robust-04	Titles	2	0.272	0.461	0.410
BM25-Span	Robust-04	Titles	3	0.262	0.425	0.369
BM25-Span	Robust-04	Titles	4	0.238	0.405	0.370
BM25-Span	Robust-04	Titles	Joint	0.263	0.423	0.373
BM25-Span	Robust-04	Titles	Avg.	0.264	0.423	0.373
BM25-Span	Robust-04	Titles	Oracle	0.264	0.424	0.374
BM25-Span	Robust-04	Desc.	0	0.268	0.416	0.348
BM25-Span	Robust-04	Desc.	1	0.251	0.398	0.332
BM25-Span	Robust-04	Desc.	2	0.243	0.404	0.332
BM25-Span	Robust-04	Desc.	3	0.224	0.397	0.367
BM25-Span	Robust-04	Desc.	4	0.229	0.357	0.285
BM25-Span	Robust-04	Desc.	Joint	0.243	0.394	0.333
BM25-Span	Robust-04	Desc.	Avg.	0.244	0.395	0.333
BM25-Span	Robust-04	Desc.	Oracle	0.244	0.394	0.333
BM25-Span	GOV2	Titles	0	0.337	0.429	0.527
BM25-Span	GOV2	Titles	1	0.372	0.461	0.603
BM25-Span	GOV2	Titles	2	0.369	0.462	0.602
BM25-Span	GOV2	Titles	3	0.297	0.427	0.508
BM25-Span	GOV2	Titles	4	0.303	0.478	0.560
BM25-Span	GOV2	Titles	Joint	0.336	0.451	0.560
BM25-Span	GOV2	Titles	Avg.	0.336	0.450	0.558
BM25-Span	GOV2	Titles	Oracle	0.336	0.452	0.561
BM25-Span	GOV2	Desc.	0	0.220	0.381	0.445
BM25-Span	GOV2	Desc.	1	0.287	0.438	0.540
BM25-Span	GOV2	Desc.	2	0.271	0.438	0.480
BM25-Span	GOV2	Desc.	3	0.335	0.445	0.623
BM25-Span	GOV2	Desc.	4	0.254	0.349	0.462
BM25-Span	GOV2	Desc.	Joint	0.274	0.410	0.510
BM25-Span	GOV2	Desc.	Avg.	0.275	0.413	0.514
BM25-Span	GOV2	Desc.	Oracle	0.275	0.413	0.514
BM25-Span	ClueWeb-09-B	Titles	0	0.120	0.216	0.372
BM25-Span	ClueWeb-09-B	Titles	1	0.101	0.208	0.332
BM25-Span	ClueWeb-09-B	Titles	2	0.125	0.328	0.432
BM25-Span	ClueWeb-09-B	Titles	3	0.099	0.246	0.317
BM25-Span	ClueWeb-09-B	Titles	4	0.082	0.134	0.225
BM25-Span	ClueWeb-09-B	Titles	Joint	0.105	0.226	0.335
BM25-Span	ClueWeb-09-B	Titles	Avg.	0.110	0.248	0.356
BM25-Span	ClueWeb-09-B	Titles	Oracle	0.110	0.249	0.360
BM25-Span	ClueWeb-09-B	Desc.	0	0.055	0.160	0.215
BM25-Span	ClueWeb-09-B	Desc.	1	0.084	0.202	0.240
BM25-Span	ClueWeb-09-B	Desc.	2	0.117	0.244	0.279
BM25-Span	ClueWeb-09-B	Desc.	3	0.115	0.277	0.387
BM25-Span	ClueWeb-09-B	Desc.	4	0.054	0.140	0.181

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Model	Coll.	Query Set	Fold	MAP	nDCG@20	P@20
BM25-Span	ClueWeb-09-B	Desc.	Joint	0.085	0.205	0.261
BM25-Span	ClueWeb-09-B	Desc.	Avg.	0.087	0.212	0.272
BM25-Span	ClueWeb-09-B	Desc.	Oracle	0.088	0.216	0.272

5 Statistical Tests

In this final section, we present p -values computed using Fisher’s randomization test to compare the performance of QL, SDM, and WSDM-Internal, to each of the other retrieval models. The statistical test is performed over the joint results, for each collection and query set, for the MAP metric. The collections, query sets and this retrieval metric are all based on TREC tracks¹. Significant improvements over the paired model, for each comparison pair, is highlighted in bold.

Model 1	Model 2	Coll.	Query Set	p -value
<i>Robust-04, Titles</i>				
QL	SDM	Robust-04	Titles	0.000
QL	Uni+O234	Robust-04	Titles	0.001
QL	Uni+O234+U2	Robust-04	Titles	0.000
QL	Uni+O23+U23	Robust-04	Titles	0.000
QL	WSDM	Robust-04	Titles	0.000
QL	WSDM-Int	Robust-04	Titles	0.000
QL	WSDM-Int-3	Robust-04	Titles	0.000
QL	PLM	Robust-04	Titles	0.487
QL	PLM-2	Robust-04	Titles	0.001
QL	PL2	Robust-04	Titles	0.232
QL	pDFR-BiL2	Robust-04	Titles	0.006
QL	pDFR-PL2	Robust-04	Titles	0.003
QL	BM25	Robust-04	Titles	0.216
QL	BM25-TP	Robust-04	Titles	0.005
QL	BM25-TP2	Robust-04	Titles	0.775
QL	BM25-Span	Robust-04	Titles	0.000
SDM	Uni+O234	Robust-04	Titles	0.911
SDM	Uni+O234+U2	Robust-04	Titles	0.570
SDM	Uni+O23+U23	Robust-04	Titles	0.375
SDM	WSDM	Robust-04	Titles	0.000
SDM	WSDM-Int	Robust-04	Titles	0.003
SDM	WSDM-Int-3	Robust-04	Titles	0.000
SDM	PLM	Robust-04	Titles	1.000
SDM	PLM-2	Robust-04	Titles	0.991
SDM	PL2	Robust-04	Titles	0.998
SDM	pDFR-BiL2	Robust-04	Titles	0.963
SDM	pDFR-PL2	Robust-04	Titles	0.933
SDM	BM25	Robust-04	Titles	0.991
SDM	BM25-TP	Robust-04	Titles	0.628
SDM	BM25-TP2	Robust-04	Titles	1.000
SDM	BM25-Span	Robust-04	Titles	0.520
WSDM-Int	Uni+O234	Robust-04	Titles	1.000

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¹<http://trec.nist.gov/>

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Model (Baseline)	Model (Treatment)	Coll.	Query Set	p-value
WSDM-Int	Uni+O234+U2	Robust-04	Titles	0.998
WSDM-Int	Uni+O23+U23	Robust-04	Titles	0.998
WSDM-Int	WSDM	Robust-04	Titles	0.000
WSDM-Int	WSDM-Int-3	Robust-04	Titles	0.001
WSDM-Int	PLM	Robust-04	Titles	1.000
WSDM-Int	PLM-2	Robust-04	Titles	1.000
WSDM-Int	PL2	Robust-04	Titles	1.000
WSDM-Int	pDFR-BiL2	Robust-04	Titles	0.999
WSDM-Int	pDFR-PL2	Robust-04	Titles	0.999
WSDM-Int	BM25	Robust-04	Titles	1.000
WSDM-Int	BM25-TP	Robust-04	Titles	0.985
WSDM-Int	BM25-TP2	Robust-04	Titles	1.000
WSDM-Int	BM25-Span	Robust-04	Titles	0.959
<i>Robust-04, Desc.</i>				
QL	SDM	Robust-04	Desc.	0.000
QL	Uni+O234	Robust-04	Desc.	0.000
QL	Uni+O234+U2	Robust-04	Desc.	0.000
QL	Uni+O23+U23	Robust-04	Desc.	0.000
QL	Uni+O234+U234	Robust-04	Desc.	0.000
QL	WSDM	Robust-04	Desc.	0.000
QL	WSDM-Int	Robust-04	Desc.	0.000
QL	WSDM-Int-3	Robust-04	Desc.	0.000
QL	PLM	Robust-04	Desc.	0.051
QL	PLM-2	Robust-04	Desc.	0.000
QL	PL2	Robust-04	Desc.	1.000
QL	pDFR-BiL2	Robust-04	Desc.	0.974
QL	pDFR-PL2	Robust-04	Desc.	0.951
QL	BM25	Robust-04	Desc.	0.962
QL	BM25-TP	Robust-04	Desc.	0.601
QL	BM25-TP2	Robust-04	Desc.	1.000
QL	BM25-Span	Robust-04	Desc.	0.587
SDM	Uni+O234	Robust-04	Desc.	0.559
SDM	Uni+O234+U2	Robust-04	Desc.	0.026
SDM	Uni+O23+U23	Robust-04	Desc.	0.100
SDM	Uni+O234+U234	Robust-04	Desc.	0.151
SDM	WSDM	Robust-04	Desc.	0.000
SDM	WSDM-Int	Robust-04	Desc.	0.000
SDM	WSDM-Int-3	Robust-04	Desc.	0.000
SDM	PLM	Robust-04	Desc.	0.982
SDM	PLM-2	Robust-04	Desc.	0.289
SDM	PL2	Robust-04	Desc.	1.000
SDM	pDFR-BiL2	Robust-04	Desc.	1.000
SDM	pDFR-PL2	Robust-04	Desc.	1.000
SDM	BM25	Robust-04	Desc.	1.000
SDM	BM25-TP	Robust-04	Desc.	0.999
SDM	BM25-TP2	Robust-04	Desc.	1.000
SDM	BM25-Span	Robust-04	Desc.	1.000
WSDM-Int	Uni+O234	Robust-04	Desc.	1.000
WSDM-Int	Uni+O234+U2	Robust-04	Desc.	1.000
WSDM-Int	Uni+O23+U23	Robust-04	Desc.	1.000
WSDM-Int	Uni+O234+U234	Robust-04	Desc.	1.000
WSDM-Int	WSDM	Robust-04	Desc.	0.000

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Model (Baseline)	Model (Treatment)	Coll.	Query Set	p-value
WSDM-Int	WSDM-Int-3	Robust-04	Desc.	0.049
WSDM-Int	PLM	Robust-04	Desc.	1.000
WSDM-Int	PLM-2	Robust-04	Desc.	1.000
WSDM-Int	PL2	Robust-04	Desc.	1.000
WSDM-Int	pDFR-BiL2	Robust-04	Desc.	1.000
WSDM-Int	pDFR-PL2	Robust-04	Desc.	1.000
WSDM-Int	BM25	Robust-04	Desc.	1.000
WSDM-Int	BM25-TP	Robust-04	Desc.	1.000
WSDM-Int	BM25-TP2	Robust-04	Desc.	1.000
WSDM-Int	BM25-Span	Robust-04	Desc.	1.000
<i>GOV2, Titles</i>				
QL	SDM	GOV2	Titles	0.000
QL	Uni+O234	GOV2	Titles	0.000
QL	Uni+O234+U2	GOV2	Titles	0.000
QL	Uni+O23+U23	GOV2	Titles	0.000
QL	WSDM	GOV2	Titles	0.000
QL	WSDM-Int	GOV2	Titles	0.000
QL	WSDM-Int-3	GOV2	Titles	0.000
QL	PLM	GOV2	Titles	0.007
QL	PLM-2	GOV2	Titles	0.171
QL	PL2	GOV2	Titles	0.301
QL	pDFR-BiL2	GOV2	Titles	0.000
QL	pDFR-PL2	GOV2	Titles	0.000
QL	BM25	GOV2	Titles	0.393
QL	BM25-TP	GOV2	Titles	0.003
QL	BM25-TP2	GOV2	Titles	0.974
QL	BM25-Span	GOV2	Titles	0.000
SDM	Uni+O234	GOV2	Titles	1.000
SDM	Uni+O234+U2	GOV2	Titles	0.972
SDM	Uni+O23+U23	GOV2	Titles	0.662
SDM	WSDM	GOV2	Titles	0.038
SDM	WSDM-Int	GOV2	Titles	0.160
SDM	WSDM-Int-3	GOV2	Titles	0.091
SDM	PLM	GOV2	Titles	1.000
SDM	PLM-2	GOV2	Titles	1.000
SDM	PL2	GOV2	Titles	1.000
SDM	pDFR-BiL2	GOV2	Titles	0.996
SDM	pDFR-PL2	GOV2	Titles	0.994
SDM	BM25	GOV2	Titles	1.000
SDM	BM25-TP	GOV2	Titles	0.785
SDM	BM25-TP2	GOV2	Titles	1.000
SDM	BM25-Span	GOV2	Titles	0.024
WSDM-Int	Uni+O234	GOV2	Titles	1.000
WSDM-Int	Uni+O234+U2	GOV2	Titles	0.929
WSDM-Int	Uni+O23+U23	GOV2	Titles	0.847
WSDM-Int	WSDM	GOV2	Titles	0.021
WSDM-Int	WSDM-Int-3	GOV2	Titles	0.237
WSDM-Int	PLM	GOV2	Titles	1.000
WSDM-Int	PLM-2	GOV2	Titles	1.000
WSDM-Int	PL2	GOV2	Titles	1.000
WSDM-Int	pDFR-BiL2	GOV2	Titles	0.999
WSDM-Int	pDFR-PL2	GOV2	Titles	0.997

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Model (Baseline)	Model (Treatment)	Coll.	Query Set	p-value
WSDM-Int	BM25	GOV2	Titles	1.000
WSDM-Int	BM25-TP	GOV2	Titles	0.936
WSDM-Int	BM25-TP2	GOV2	Titles	1.000
WSDM-Int	BM25-Span	GOV2	Titles	0.089
<i>GOV2, Desc.</i>				
QL	SDM	GOV2	Desc.	0.000
QL	Uni+O234	GOV2	Desc.	0.000
QL	Uni+O234+U2	GOV2	Desc.	0.000
QL	Uni+O23+U23	GOV2	Desc.	0.000
QL	Uni+O234+U234	GOV2	Desc.	0.000
QL	WSDM	GOV2	Desc.	0.000
QL	WSDM-Int	GOV2	Desc.	0.000
QL	WSDM-Int-3	GOV2	Desc.	0.000
QL	PLM	GOV2	Desc.	0.945
QL	PLM-2	GOV2	Desc.	0.000
QL	PL2	GOV2	Desc.	0.352
QL	pDFR-BiL2	GOV2	Desc.	0.020
QL	pDFR-PL2	GOV2	Desc.	0.002
QL	BM25	GOV2	Desc.	0.267
QL	BM25-TP	GOV2	Desc.	0.017
QL	BM25-TP2	GOV2	Desc.	0.998
QL	BM25-Span	GOV2	Desc.	0.003
SDM	Uni+O234	GOV2	Desc.	0.996
SDM	Uni+O234+U2	GOV2	Desc.	0.358
SDM	Uni+O23+U23	GOV2	Desc.	0.896
SDM	Uni+O234+U234	GOV2	Desc.	0.809
SDM	WSDM	GOV2	Desc.	0.000
SDM	WSDM-Int	GOV2	Desc.	0.000
SDM	WSDM-Int-3	GOV2	Desc.	0.000
SDM	PLM	GOV2	Desc.	1.000
SDM	PLM-2	GOV2	Desc.	0.947
SDM	PL2	GOV2	Desc.	1.000
SDM	pDFR-BiL2	GOV2	Desc.	1.000
SDM	pDFR-PL2	GOV2	Desc.	0.999
SDM	BM25	GOV2	Desc.	0.999
SDM	BM25-TP	GOV2	Desc.	0.988
SDM	BM25-TP2	GOV2	Desc.	1.000
SDM	BM25-Span	GOV2	Desc.	0.948
WSDM-Int	Uni+O234	GOV2	Desc.	1.000
WSDM-Int	Uni+O234+U2	GOV2	Desc.	1.000
WSDM-Int	Uni+O23+U23	GOV2	Desc.	1.000
WSDM-Int	Uni+O234+U234	GOV2	Desc.	1.000
WSDM-Int	WSDM	GOV2	Desc.	0.029
WSDM-Int	WSDM-Int-3	GOV2	Desc.	0.860
WSDM-Int	PLM	GOV2	Desc.	1.000
WSDM-Int	PLM-2	GOV2	Desc.	1.000
WSDM-Int	PL2	GOV2	Desc.	1.000
WSDM-Int	pDFR-BiL2	GOV2	Desc.	1.000
WSDM-Int	pDFR-PL2	GOV2	Desc.	1.000
WSDM-Int	BM25	GOV2	Desc.	1.000
WSDM-Int	BM25-TP	GOV2	Desc.	1.000
WSDM-Int	BM25-TP2	GOV2	Desc.	1.000

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Model (Baseline)	Model (Treatment)	Coll.	Query Set	<i>p</i> -value
WSDM-Int	BM25-Span	GOV2	Desc.	1.000
<i>ClueWeb-09-B, Titles</i>				
QL	SDM	ClueWeb-09-B	Titles	0.000
QL	Uni+O234	ClueWeb-09-B	Titles	0.000
QL	Uni+O234+U2	ClueWeb-09-B	Titles	0.000
QL	Uni+O23+U23	ClueWeb-09-B	Titles	0.002
QL	WSDM	ClueWeb-09-B	Titles	0.000
QL	WSDM-Int	ClueWeb-09-B	Titles	0.000
QL	WSDM-Int-3	ClueWeb-09-B	Titles	0.000
QL	PLM	ClueWeb-09-B	Titles	0.944
QL	PLM-2	ClueWeb-09-B	Titles	0.604
QL	PL2	ClueWeb-09-B	Titles	0.000
QL	pDFR-BiL2	ClueWeb-09-B	Titles	0.000
QL	pDFR-PL2	ClueWeb-09-B	Titles	0.000
QL	BM25	ClueWeb-09-B	Titles	0.365
QL	BM25-TP	ClueWeb-09-B	Titles	0.002
QL	BM25-TP2	ClueWeb-09-B	Titles	0.301
QL	BM25-Span	ClueWeb-09-B	Titles	0.025
SDM	Uni+O234	ClueWeb-09-B	Titles	0.642
SDM	Uni+O234+U2	ClueWeb-09-B	Titles	0.229
SDM	Uni+O23+U23	ClueWeb-09-B	Titles	0.595
SDM	WSDM	ClueWeb-09-B	Titles	0.030
SDM	WSDM-Int	ClueWeb-09-B	Titles	0.000
SDM	WSDM-Int-3	ClueWeb-09-B	Titles	0.067
SDM	PLM	ClueWeb-09-B	Titles	1.000
SDM	PLM-2	ClueWeb-09-B	Titles	1.000
SDM	PL2	ClueWeb-09-B	Titles	0.842
SDM	pDFR-BiL2	ClueWeb-09-B	Titles	0.984
SDM	pDFR-PL2	ClueWeb-09-B	Titles	0.037
SDM	BM25	ClueWeb-09-B	Titles	0.979
SDM	BM25-TP	ClueWeb-09-B	Titles	0.391
SDM	BM25-TP2	ClueWeb-09-B	Titles	0.962
SDM	BM25-Span	ClueWeb-09-B	Titles	0.774
WSDM-Int	Uni+O234	ClueWeb-09-B	Titles	1.000
WSDM-Int	Uni+O234+U2	ClueWeb-09-B	Titles	0.973
WSDM-Int	Uni+O23+U23	ClueWeb-09-B	Titles	0.990
WSDM-Int	WSDM	ClueWeb-09-B	Titles	0.985
WSDM-Int	WSDM-Int-3	ClueWeb-09-B	Titles	0.891
WSDM-Int	PLM	ClueWeb-09-B	Titles	1.000
WSDM-Int	PLM-2	ClueWeb-09-B	Titles	1.000
WSDM-Int	PL2	ClueWeb-09-B	Titles	0.999
WSDM-Int	pDFR-BiL2	ClueWeb-09-B	Titles	1.000
WSDM-Int	pDFR-PL2	ClueWeb-09-B	Titles	0.739
WSDM-Int	BM25	ClueWeb-09-B	Titles	0.999
WSDM-Int	BM25-TP	ClueWeb-09-B	Titles	0.852
WSDM-Int	BM25-TP2	ClueWeb-09-B	Titles	0.998
WSDM-Int	BM25-Span	ClueWeb-09-B	Titles	0.973
<i>ClueWeb-09-B, Desc.</i>				
QL	SDM	ClueWeb-09-B	Desc.	0.250
QL	Uni+O234	ClueWeb-09-B	Desc.	0.498
QL	Uni+O234+U2	ClueWeb-09-B	Desc.	0.055
QL	Uni+O23+U23	ClueWeb-09-B	Desc.	0.402

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Model (Baseline)	Model (Treatment)	Coll.	Query Set	<i>p</i> -value
QL	Uni+O234+U234	ClueWeb-09-B	Desc.	0.118
QL	WSDM	ClueWeb-09-B	Desc.	0.000
QL	WSDM-Int	ClueWeb-09-B	Desc.	0.003
QL	WSDM-Int-3	ClueWeb-09-B	Desc.	0.026
QL	PLM	ClueWeb-09-B	Desc.	0.999
QL	PLM-2	ClueWeb-09-B	Desc.	0.315
QL	PL2	ClueWeb-09-B	Desc.	0.025
QL	pDFR-BiL2	ClueWeb-09-B	Desc.	0.107
QL	pDFR-PL2	ClueWeb-09-B	Desc.	0.015
QL	BM25	ClueWeb-09-B	Desc.	0.012
QL	BM25-TP	ClueWeb-09-B	Desc.	0.000
QL	BM25-TP2	ClueWeb-09-B	Desc.	0.583
QL	BM25-Span	ClueWeb-09-B	Desc.	0.000
SDM	Uni+O234	ClueWeb-09-B	Desc.	0.991
SDM	Uni+O234+U2	ClueWeb-09-B	Desc.	0.238
SDM	Uni+O23+U23	ClueWeb-09-B	Desc.	0.931
SDM	Uni+O234+U234	ClueWeb-09-B	Desc.	0.246
SDM	WSDM	ClueWeb-09-B	Desc.	0.003
SDM	WSDM-Int	ClueWeb-09-B	Desc.	0.147
SDM	WSDM-Int-3	ClueWeb-09-B	Desc.	0.290
SDM	PLM	ClueWeb-09-B	Desc.	0.999
SDM	PLM-2	ClueWeb-09-B	Desc.	0.641
SDM	PL2	ClueWeb-09-B	Desc.	0.549
SDM	pDFR-BiL2	ClueWeb-09-B	Desc.	0.607
SDM	pDFR-PL2	ClueWeb-09-B	Desc.	0.313
SDM	BM25	ClueWeb-09-B	Desc.	0.271
SDM	BM25-TP	ClueWeb-09-B	Desc.	0.071
SDM	BM25-TP2	ClueWeb-09-B	Desc.	0.901
SDM	BM25-Span	ClueWeb-09-B	Desc.	0.025
WSDM-Int	Uni+O234	ClueWeb-09-B	Desc.	0.977
WSDM-Int	Uni+O234+U2	ClueWeb-09-B	Desc.	0.816
WSDM-Int	Uni+O23+U23	ClueWeb-09-B	Desc.	0.936
WSDM-Int	Uni+O234+U234	ClueWeb-09-B	Desc.	0.782
WSDM-Int	WSDM	ClueWeb-09-B	Desc.	0.005
WSDM-Int	WSDM-Int-3	ClueWeb-09-B	Desc.	0.958
WSDM-Int	PLM	ClueWeb-09-B	Desc.	1.000
WSDM-Int	PLM-2	ClueWeb-09-B	Desc.	0.996
WSDM-Int	PL2	ClueWeb-09-B	Desc.	0.957
WSDM-Int	pDFR-BiL2	ClueWeb-09-B	Desc.	0.980
WSDM-Int	pDFR-PL2	ClueWeb-09-B	Desc.	0.718
WSDM-Int	BM25	ClueWeb-09-B	Desc.	0.645
WSDM-Int	BM25-TP	ClueWeb-09-B	Desc.	0.289
WSDM-Int	BM25-TP2	ClueWeb-09-B	Desc.	0.969
WSDM-Int	BM25-Span	ClueWeb-09-B	Desc.	0.189

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