

	RWR-Pseudo	RWR-Base	RWR-Base
RWR-Combo (performs better than)	0.06 (p-value = 0.002)	0.22 (p-value < 0.001)	0.18 (p-value < 0.001)
RWR-Pseudo (performs better than)	/	0.16 (p-value < 0.001)	0.12 (p-value = 0.003)
RW-Back (performs better than)	/	/	0.04 (p-value = 0.11)*

*: insignificance of the comparison results.

Table 3: Statistical significance test on performance improvement of the four algorithms in comparison. Each entry contains the relative precision increase as well as the p-value. A p-value of less than 0.05 indicates a significance improvement.

Query	RWR-Base	RW-Back	RWR-Pseudo	RWR-Combo
valentine one (shopping & car)	valentines day valentine activities valentine gifts anniversary gifts free valentines crafts	valentine activities valentine gifts valentines day free valentines crafts anniversary gifts	valentine gifts valentine one review radar detector valentine one ebay valentine activities	best radar detector escort radar radar detector valentine one review valentine one ebay
single ladies (music)	beyonce single ladies single women single women myspace eharmony	single women dating single ladies dating ladies dating ladies myspace single moms	single ladies by beyonce single ladies mp3 dating single ladies single ladies myspace beyonce single ladies	beyonce single ladies single ladies by beyonce single ladies lyrics single ladies mp3 single ladies download
nfl teams with 5 super bowl wins (sports & long)	super bowl champions super bowl super bowl 2009 super bowl 2008	super bowl 2009 super bowl 2008 super bowl champs list of superbowl	super bowl history super bowl winners past nfl super bowl winner super bowl 2009	list super bowl winners super bowl winners super bowl steelers past nfl super bowl winner
dc ups (ambiguous)	d-cups d cup dc ups systems d-cup dc control	dc power d-cups dc ups systems dc power system universal power supply	dc power supply dc ups power d-cups dc ups systems dc usa	dc power dc ups power dc postal service dc power supply dc ups systems

Table 4: Examples of query suggestions by four different algorithms. Bold queries are judged as relevant. Our algorithm RWR-Combo has the most number of relevant suggestions in all four cases. RWR-Combo is also capable of diversifying the suggestions to multi-intensional queries.

(0.85) as used in the pagerank algorithm. To summarize, a simplified way of leveraging our model to make suggestion for rare queries can be conducted as follows (the parameters are specified for the cut-off value of 20 for query frequency):

1. perform random walk with p around 0.85 on click and skip graphs respectively,
2. multiple the positive ranking matrix \mathbf{R}^+ by 0.75, the negative ranking matrix \mathbf{R}^- by 0.25, respectively,
3. combine \mathbf{R}^+ and \mathbf{R}^- linearly to get \mathbf{R}^{opt} and extract the optimal query correlation matrix \mathbf{Q}^{opt} .

In our empirical analysis, when a query set contains more frequent queries, the skip graph becomes less important during the smoothing process. We ran three tests to obtain the optimal values of α and p on three different datasets, with query frequency cut-off values of 20, 50 and 100 respectively. Figure 12 shows the bar plots in terms of the best parameter values. There is an obvious up trend of α values when the query frequency increases, while for the restarting value p , it stabilizes relatively around 0.85.

5. CONCLUSION AND FUTURE WORK

In this paper, we proposed an optimal solution for rare query suggestions. Rare queries are those difficult (long-

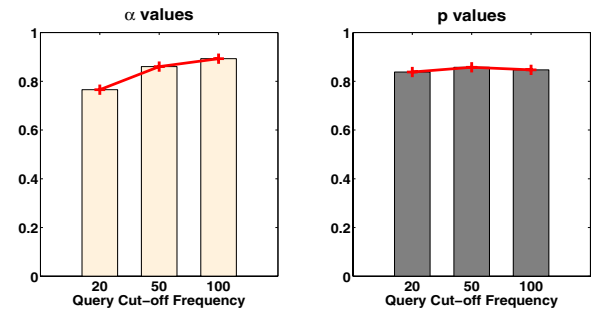


Figure 12: Optimal values of parameters w.r.t. different query frequency cut-offs. α value increases with the query frequency, while p is not correlated with the query frequency.

tail) queries in search engines that appeared very few times. We proposed to tackle this problem by random walk on the query logs. Specifically, we leveraged both click and skip information from query log to form an optimal random walk and combination model. Our model was related to both pseudo-relevance feedback and smoothing technique used in natural language processing. Our major discovery was that user skipped URLs (observed by users but without clicks)