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The Solitude of Relevant Documents in the Pool

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ABSTRACT
Pool bias is a well understood problem of test-collection based benchmarking in information retrieval. The pooling method itself is designed to identify all relevant documents. In practice, ‘all’ translates to ‘as many as possible given some budgetary constraints’ and the problem persists, albeit mitigated. Recently, methods to address this pool bias for previously created test collections have been proposed, for the evaluation measure precision at cut-off ($P@n$). Analyzing previous methods, we make the empirical observation that the distribution of the probability of providing new relevant documents to the pool, over the runs, is log-normal (when the pooling strategy is fixed depth at cut-off). We use this observation to calculate a prior probability of providing new relevant documents, which we then use in a pool bias estimator that improves upon previous estimates of precision at cut-off. Through extensive experimental results, covering 15 test collections, we show that the proposed bias correction method is the new state of the art, providing the closest estimates yet when compared to the original pool.

Keywords
Pool bias, $P@n$, test collections, TREC

1. INTRODUCTION
The pool bias refers to an undesirable side effect caused by the use of the pooling method. This bias manifests itself by the discounting of Information Retrieval (IR) systems when tested on previously built test collections, due to the retrieval of potentially relevant but non-judged documents [4].

An IR test collection is composed of: a collection of documents, a set of topics, and ideally a complete set of paired relations between topics and documents called relevance assessments, which indicate whether a document is either relevant or non-relevant for a given topic. Soon in the history of IR, with the explosion in size of the document collections and therefore of the number of relevance assessments required, the building of such test collections became impractical; to address this issue, the pooling method was introduced [9].

The main advantage of the pooling method is to limit the number of relevance assessments through the use of previously collected search results provided by various retrieval systems. The first introduced and most commonly used pooling strategy is the fixed-depth at $n$. This strategy consists in selecting the top $n$ documents retrieved by each retrieval system, then collecting them in a set, called the pool, which later will be fully judged. Although its main limitation is due the introduced incompleteness of the relevance assessments, as pointed out by Spärck Jones [3], the aim of the pooling method is not to find all the relevant documents but an unbiased sample of them. However, this is not an easy problem because, in the absence of full evaluation, and in the presence of millions of potentially relevant documents, there is no guarantee that a future retrieval method will not retrieve completely different yet relevant documents.

There are three ways to mitigate the pool bias: 1) increasing the depth of the pool, 2) increasing the number of topics, which would reduce the variance and, 3) increasing the number of pooled runs, which should increase the diversity of the pooled documents. Each of them has as effect an increment on the number of judgments to be performed. However, only the first two solutions are directly controllable by the test collection builder, leaving the third to the participation of the IR community in solving the challenge for which the test collection is going to be built.

To tackle the pool bias issue, the IR community has pursued two research paths, one developing pooling strategies aimed at mitigating the pool bias when creating new test collections [2, 8, 7] and the other, developing pool bias estimators aimed at correcting the observed pool bias on existing test collections. Witnessing an explosion in the number of test collections developed each year that use the pooling method with fixed-depth at $n$ pooling strategy and an increasing bias due to an increasing trend in the creation of test collections for niche domain-specific IR, where a required minimal participation is usually not met, in this paper we extend the work done on the latter research path. We develop a new pool bias estimator for the metric Precision at cut-off ($P@n$) based on empirical observations. There are two reasons for working with such a simple metric: there is an increasing demand from practitioners for metrics that make ‘sense’ [1], and it is a corner stone for other more complex metrics.

2. BACKGROUND
Webber and Park [10] introduced a method to correct the pool bias, which they tested on Rank-Biased-Precision at cut-off but claimed to work also with $P@n$. This method adds to the score of a new run a coefficient equal to the mean difference, indicated with $\delta P@n$, between the score obtained when a run, initially part of the pool...
$R_p$, is pooled and not-pooled:

$$\delta P@n(r_p) = P@n(r_p, Q^{R_p}) - P@n(r_p, Q^{R_p\setminus(r_p)})$$  \hspace{1cm} (1)$$

The correction coefficient for a run ($r_u \notin R_p$) is the expectation:

$$E_{r_p \in R_p}[\delta P@n(r_p)]$$  \hspace{1cm} (2)$$

where $Q^{R_p}$ is the set of judged documents created using the set of pooled runs $R_p$. This approach assumes that any given new run is sampled from the same distribution as the pooled ones. This is of course not always true, because runs are selected based on their performance by human intervention. A limitation of this approach is that it computes a coefficient that is constant and therefore does not depend on the actual status of the biased run. Another limitation of this approach is that the correction is not bounded by the tested runs, thereby we may have a score that may exceed the upper limit of this approach.

To find a better estimate, we look at the ratio between the number of non-relevant documents and the number of non-judged documents over $n$ times the maximum likelihood estimator for the proportion $\bar{r}$ of the biased run. This makes the estimate for the correction biased for a new run because the distribution of runs is not centered on the calculated mean.

To find a better estimate, we look at the ratio between the number of uniquely identified relevant documents discovered by pooling the run $r_p$ and the number of non-judged documents that the run would have had if it had not been pooled. This quantity may be interpreted as the probability of the non-judged documents of the run to be relevant:

$$P(d \in [r_p] | Q^{R_p\setminus(r_p)}, d \in Q^{R_p}) = \frac{P@n(r_p, Q^{R_p\setminus(r_p)})}{P@n(r_p, Q^{R_p}) + P@n(r_p, Q^{R_p\setminus(r_p)})} = \frac{\delta P@n(r_p)}{E'@n(r_p)}$$  \hspace{1cm} (3)$$

where we use the notation introduced by Lipani et al. [5]: $E'@n$ is the ratio between the number of non-judged documents and $n$ when $r_p$ is not in the pool; $P@n$ is the anti-precision at cut-off, also known in statistics as the false discovery rate, the ratio between the number of non-relevant documents and $n$; and $Q^{R_p}$ is the set of pooled documents that are relevant. We observe empirically that its distribution is log-normal. Indicating with $X$ this distribution and with $Y$ its log-transformation $Y = \ln(X)$, $Y$ is normally distributed. In the Q-Q plot in Fig. 1 on the bottom, we observe how the theoretical normal distribution correlates with the sample distribution. To calculate the mean of the new estimate, we compute the mean of the distribution $Y$ and then transform it back to the domain of the distribution $X$, which leads to the geometric mean of the $X$:

$$e^{E[\ln(X)]]} = e^{E[Y]} = \sqrt[|Y|]{\prod_{y \in Y} y} = GM[X]$$  \hspace{1cm} (4)$$

where GM is the geometric mean. Thereby, the correction coeffi-
of the run. In fact, one could generate an unbounded number of
corresponding the fraction in Eq. (5) is well defined. Second, such
because: first, if
Comparing Eq. (2) and Eq. (5) we notice that the numerator of
equations provided to the pool, and then multiplied by the same but for
mean.
also, and that it is not a constant number as it was before. Also,
comparing the algorithm of the Lipani approach [5], we observe
sis, we have two hypotheses for why this happens, and we claim that
happens for a combination of both. The first hypothesis
performer cases mentioned above). Here, after an empirical analy-
s, or the ones that exist bring no new information in terms
leave-one organization-out fashion. This is done to better simulate
of any similar run added to the pool by the same or-
organization. Moreover, to avoid the presence of runs produced by
the 25% of poorly performing runs are filtered out.
To measure the effectiveness of the different approaches, three
measures are used: Mean Absolute Error (MAE), System Rank
Error (SRE) and System Rank Error with statistical significance
(SRE*). MAE measures the mean of the absolute difference of
run’s scores when in the pool and when not. SRE measures the
difference in ranks between the true ranking and new ranking with
using the corrections. Finally, SRE* is similar to SRE, but counts the
difference only if statistically significant (paired t-test, \( p < 0.05 \)).
We compared the new approach with the previously mentioned
Webber and Lipani approaches, and the baseline, which is the Reduced
Pool. The Reduced Pool measures the bias we get if no
correction is provided.

4.2 Results
In Tab. 1 the full results are presented. We observe that our
approach is top performer in the majority of the cases (45 for MAE,
37 for SRE and 9 for SRE*), with some worst results (15 for MAE,
16 for SRE and, 6 for SRE*) mostly obtained on Ad Hoc 7 and
Ad Hoc 8, where the Lipani approach performs better. The Lipani
approach, although in general it is not as good as our approach,
which has a more stable behavior, collecting fewer worst results
(9 for MAE, 6 for SRE and, 1 for SRE*). The Webber approach and
the Reduced Pool are the ones that get the majority of the worst
results, as also demonstrated in previous work [5].
When our approach is applied to the test collections: Ad Hoc 3,
Ad Hoc 5, Ad Hoc 7, Ad Hoc 8, Web 9, Web 2002, Genomics
2005 and Microblog 2011 we can observe that the MAE for the
correction applied to \( P_{@5} \) gets the worst score (8 of the 15 worst
performer cases mentioned above). Here, after an empirical analy-
sis, we have two hypotheses for why this happens, and we claim that
it happens for a combination of both. The first hypothesis
relies on the observation that for such test collections, the ratio
between the number of pooled runs and the number of organiza-
tions is much greater than 1. This means that multiple runs from
the same organization have been pooled and therefore contribute a
very similar set of documents to the pool. Thereby, it nullifies the
leave-one run-out approach embedded in our and the Webber meth-
ods, as shown in Eq. (2) and (5), looking inside E in the first
and GM in the second equation, when the run \( r_p \), originally in the pool
\( Q_{@P} \) is removed from the pool (\( Q_{@P \setminus \{r_p\}} \)). Note that this leave-
one run-out approach inside the algorithm and is different from the
leave-one organization-out testing procedure that happens before the
algorithm is triggered. However, for Legal 2006 and Medical
2011, although the ratio is also large, we may not observe the same
effect due the more shallow pool depth. The second hypothesis is
that when we want to count the top number of relevant documents
of a run and we have such large number of relevance judgments,
there is a high likelihood that the top documents of every run have
been already pooled by other runs. This means that, as for the
first hypothesis, the effect of the leave-one run-out embedded in
the method is nullified. We split these two hypotheses because they
have a different nature, although they have the same effect that can
be mitigated by the same solution.
In general, these two hypotheses cause a significant error due to the
fact that the number of points collected in order to compute an
unbiased estimate of the geometric mean is insufficient. When these
sets are small, it means that either there are no non-judged doc-
ments, or the ones that exist bring no new information in terms

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**Algorithm 1 Revised estimator based on the Webber approach**

\[ r_u \leftarrow \text{unpooled run} \]
\[ R_p \leftarrow \text{set of pooled runs} \]
\[ T \leftarrow \text{set of topics} \]
\[ Q \leftarrow \text{qrels on } T \text{ derived from } R_p \]
\[ s_{r_u} \leftarrow P_{@m}(r_u, Q) \]
\[ k_{r_u} \leftarrow 1 - (s_{r_u} + P_{@m}(r_u, Q)) \]

for all \( r_p \in R_p \)

\[ R'_p \leftarrow R_p \setminus \{r_p\} \]
\[ Q' \leftarrow \text{qrels on } T \text{ derived from } R'_p \]
\[ s'_{r_p} \leftarrow P_{@m}(r_p, Q') \]
\[ \delta P_{r_p} \leftarrow P_{@m}(r_p, Q) - s'_{r_p} \]
\[ k'_{r_p} \leftarrow 1 - (s'_{r_p} + P_{@m}(r_p, Q')) \]
end for

\[ a \leftarrow k_{r_u} \cdot \text{GM}_{r_p \in \{r_p \}} \left[ \delta P_{r_p} / k'_{r_p} \right] \]

return \( s_{r_u} + a \)

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of being or not being in the pool. Thereby, the error introduced is bigger than the one we would have observed if we had not corrected the run at all. In fact we can observe that the second best result, but for Genomics 2005, excluding the Lipani approach, is obtained by the Reduced Pool. Therefore to mitigate this effect, it is necessary to introduce a trigger that checks if the number of data points collected are sufficient to compute the estimate and perform the correction, and if not, to fall back to the Reduced Pool error.

## 5. CONCLUSION

We have presented a new approach, empirically justified, to correct the pool bias for the evaluation measure PR@n. The method is based on new insights on the fixed-depth on pooling strategy, namely the observation of a relation between the probability of a run to provide uniquely identified relevant documents to the pool and the log-normal distribution. The proposed method largely outperformed the previous approaches, although for two test collections, Ad Hoc 7 and Ad Hoc 8, where the Lipani estimator works better. We identified two hypotheses that would explain the performance difference, both of which tracing their source to situations where, for the metric at hand, the vast majority of runs have all of their documents judged in the reduced pool. A cross comparison between the algorithm of the Lipani estimator and the algorithm presented here shows some similarities which may inspire a new improvement on the correction of the pool bias.

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## 6. REFERENCES


#### Table 1: Summary of the results per test collection generated through a leave-one organization-out using the top 75% of the best performing pooled runs. With: $|R|$ number of runs submitted, $|O|$ number of organizations involved, $|J_i|$ number of pooled runs, $d$ depth of the pool and $T$ number of topics. Last row counts how many times each approach per metric performed best or worst, tie not included.

<table>
<thead>
<tr>
<th>Track/Year</th>
<th>PR@50</th>
<th>Our MAE</th>
<th>SRE MAE</th>
<th>SRE MAE</th>
<th>Webber MAE</th>
<th>Reduced Pool MAE</th>
<th>SRE MAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ad Hoc 7/2011</td>
<td>58 5 0.0109</td>
<td>3 0.0060</td>
<td>2 0.0060</td>
<td>3 0.0060</td>
<td>4 0.0060</td>
<td>5 0.0060</td>
<td>6 0.0060</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>59 5 0.0089</td>
<td>4 0.0059</td>
<td>3 0.0059</td>
<td>4 0.0059</td>
<td>5 0.0059</td>
<td>6 0.0059</td>
<td>7 0.0059</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>60 5 0.0069</td>
<td>5 0.0039</td>
<td>4 0.0039</td>
<td>5 0.0039</td>
<td>6 0.0039</td>
<td>7 0.0039</td>
<td>8 0.0039</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>61 5 0.0049</td>
<td>6 0.0029</td>
<td>5 0.0029</td>
<td>6 0.0029</td>
<td>7 0.0029</td>
<td>8 0.0029</td>
<td>9 0.0029</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>62 5 0.0039</td>
<td>7 0.0019</td>
<td>6 0.0019</td>
<td>7 0.0019</td>
<td>8 0.0019</td>
<td>9 0.0019</td>
<td>10 0.0019</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>63 5 0.0029</td>
<td>8 0.0019</td>
<td>7 0.0019</td>
<td>8 0.0019</td>
<td>9 0.0019</td>
<td>10 0.0019</td>
<td>11 0.0019</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>64 5 0.0020</td>
<td>9 0.0011</td>
<td>8 0.0011</td>
<td>9 0.0011</td>
<td>10 0.0011</td>
<td>11 0.0011</td>
<td>12 0.0011</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>65 5 0.0011</td>
<td>10 0.0011</td>
<td>9 0.0011</td>
<td>10 0.0011</td>
<td>11 0.0011</td>
<td>12 0.0011</td>
<td>13 0.0011</td>
</tr>
<tr>
<td>Ad Hoc 7/2011</td>
<td>66 5 0.0001</td>
<td>11 0.0001</td>
<td>10 0.0001</td>
<td>11 0.0001</td>
<td>12 0.0001</td>
<td>13 0.0001</td>
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<tr>
<td>Ad Hoc 7/2011</td>
<td>67 5 0.0000</td>
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<td>11 0.0000</td>
<td>12 0.0000</td>
<td>13 0.0000</td>
<td>14 0.0000</td>
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