

Removing Manually Generated Boilerplate from Electronic Texts: Experiments with Project Gutenberg e-Books*

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Abstract

Collaborative work on unstructured or semi-structured documents, such as in literature corpora or source code, often involves agreed upon templates containing metadata. These templates are not consistent across users and over time. Rule-based parsing of these templates is expensive to maintain and tends to fail as new documents are added. Statistical techniques based on frequent occurrences have the potential to identify automatically a large fraction of the templates, thus reducing the burden on the programmers. We investigate the case of the Project Gutenberg™ corpus, where most documents are in ASCII format with preambles and epilogues that are often copied and pasted or manually typed. We show that a statistical approach can solve most cases though some documents require knowledge of English. We also survey various technical solutions that make our approach applicable to large data sets.

1 Introduction

The Web has encouraged the wide distribution of collaboratively edited collections of text documents. An example is Project Gutenberg¹ [Pro09] (hereafter PG), the oldest digital library, containing over 20,000 digitized books. Meanwhile, automated text analysis is becoming more common. In any corpus of unstructured text files, including source code [AG06], we may find that some uninteresting “boilerplate” text coexists with interesting text that we wish to process. This problem also exists when trying to “scrape” information from Web

*Expanded version of [KL07]

¹Project Gutenberg is a registered trademark of the Project Gutenberg Literary Archive Foundation.

year	new eBooks
2001	1240
2002	2441
2003	4164
2004	4049
2005	3186
2006	4314

Table 1: New PG e-Books per year [Coo07]

pages [GPT05]. We are particularly interested in cases where no single template generates all text files — rather, there is an undetermined number and we do not initially know which template was used for a particular file. Some templates may differ only in trivial ways, such as in the use of white space, while other differences can be substantial — as is expected when distributed teams edit the files over several years.

Ikeda and Yamada [IY04] propose “substring amplification” to cluster files according to the templates used to generate them. The key observations are that chunks of text belonging to the template appear repeatedly in the set of files, and that a suffix tree can help detect the long and frequent strings.

Using this approach with PG is undesirable since the suffix array would consume much memory and require much processing: the total size of the files is large and growing (see Tables 1 and 2). Instead, we should use our domain knowledge: the boilerplate in PG is naturally organized in lines and only appears at the beginning or end of a document. We expect to find similar patterns in other hand-edited boilerplate.

1.1 Contribution and Organization

Section 2 presents the PG corpus and describes the difficulties in removing the preambles and epilogues, boilerplate that has been inserted manually and has evolved over time. Given the widespread use of PG, a solution to this specific problem is itself valuable. We also present a few ideas that can be leveraged; for instance, line breaking in PG boilerplate is consistent throughout the corpus. Section 3 presents the general frequent-lines algorithm we used. We show analytically that our algorithm is resilient with respect to line-classification errors in Subsection 3.2. In Subsection 3.3, various line-frequency classification strategies are presented including exact internal memory, exact external memory, checksumming, hashing, and hot-item tracking. We show that for very skewed distribution, hashing to few bits does not lead to frequent collisions and thus, it can be both accurate and fast. We also provide evidence that hot-item tracking is easier with highly skewed distributions. Finally, in Subsection 3.4, we present a few simple rule-based heuristics that can help improve our algorithm’s results. We conclude in Section 4 with an experimental evaluation of accuracy and processing speed. Benchmarking against an existing tool, we find our approach gives superior results.

Item	Typical size
Desktop memory	1 GiB
PG e-books	20,000
PG files	100,000
PG .txt files	25,000
PG size	150 GiB
PG .txt size	10 GiB
PG .txt size	200 M lines
PG line length	50 characters, average
PG avg file size	8500 lines
First DVD (2003):	
ebooks	10,000
.txt files	11,000
.txt size	5 GiB
.txt size	80 M pre-proc. lines
.txt size	55 M distinct pre-proc. lines
.txt size	10,000 freq. pre-proc. lines

Table 2: Typical size assumptions for 2007. Preprocessing, discussed in § 3.1, removes short lines.

Though we have tailored the frequent-lines approach for PG, it could be similarly tailored for other corpora with manually generated or evolving boilerplate.

1.2 Related Work

Stripping unwanted and often repeated content is a common task. Frequent patterns in text documents have been used for plagiarism detection [SGWG06], for document fingerprinting [SWA03], for removing templates in HTML documents [DMG05], and for spam detection [SCKL04]. Template detection in HTML pages has been shown to improve document retrieval [CYL06].

The algorithmics of finding frequent items or patterns has received much attention. For a survey of the stream-based algorithms, see Cormode and Muthukrishnan [CM05b, p. 253]. Finding frequent patterns robustly is possible using gap constraints [JBD05].

The specific problem of detecting preamble/epilogue templates in the PG corpus has been tackled by several hand-crafted rule-based systems [Atk04, Bur05, Gru06].

2 Stripping PG

The PG corpus contains texts in different formats, and subsets of the corpus are distributed on various media. An e-book may be available in several formats and may have been revised (for instance, to correct errors) several times. Furthermore, a given book may exist in more than one edition, since published books are frequently revised by their authors over time. An *e-book file* corresponds to a certain format, edition and version of an e-book, and this paper is primarily

concerned with e-book files, rather than e-books themselves. The number of e-book files in PG and its first DVD are given in Table 2, along with related statistics. While some of these sizes were given by PG itself [Pro06b], others were obtained by processing the DVDs, whereas yet other were extrapolated from a random sample of approximately 100 e-books.

Due to the size of the full corpus, we report on results from the first and second PG DVDs [Pro06a]. These DVDs contain most of the current text files and can be viewed as snapshots of the text portion of the archive in 2003 and 2006. With few exceptions, e-books produced by PG are available in unstructured plain text, whereas only a smaller subset are available as XML or HTML. Therefore, projects that wish to use data from PG need to work with unstructured text. However, the method by which PG e-books are created produces some challenges.

Although the first PG e-books were undoubtedly typed in manually, the production of e-books has been modernized although remaining manual. The original documents are typically in a printed form and have been scanned. Volunteers then use OCR and proof-reading tools such as the “Distributed Proofreaders” [NF03] application (see Fig. 1). The volunteers merely translate a printed document into an electronic text document: headers, tables, sections, foreign text, and so on are not marked up in the plain-text version. At some stage, boilerplate text is added.

With PG e-books, there is always a preamble that provides various standard metadata, possibly comments from the transcribers, comments about the legal status of the text, and so forth. Following the transcribed body of the book, there is frequently an epilogue that contains further information about PG, the transcribers, and so forth. Text-analysis tools are typically applied only to the body of the book; clearly, a vocabulary analysis will not wish to report on vocabulary that comes from the preamble. We want an automated solution to remove the preamble and epilogue, and we are willing to accept less than perfect accuracy in return for fast runtimes.

One additional complication is that the preamble and epilogue portions are not entirely one block of boilerplate. The names of the transcribers, the title of the book, and other variable items appear in the preamble and epilogue. Further, it appears that the preamble and epilogues are typically the result of human-guided cut-and-paste (or even re-typing) activities.

PG does specify how the preamble and the epilogue should be formatted. An e-book file *should* always begin with a specified template [Pro06c]:

```
The PG eBook, (insert title), by (insert author)
```

```
This eBook is for the use of anyone anywhere at no cost and with
almost no restrictions whatsoever. You may copy it, give it away or
re-use it under the terms of the PG License included
with this eBook or online at www.gutenberg.org
```

```
** This is a COPYRIGHTED PG eBook, Details Below **
```

```
** Please follow the copyright guidelines in this file. **
```

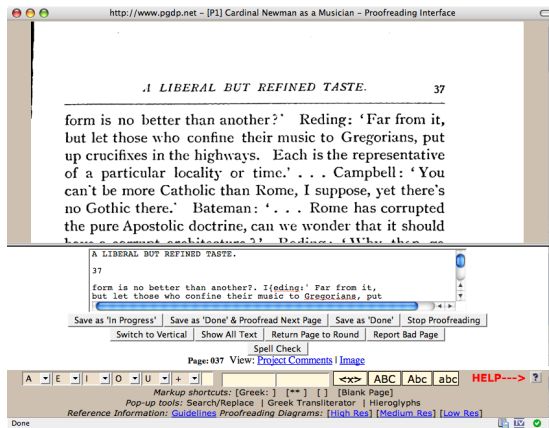


Figure 1: Screen shot of the “Distributed Proofreaders” application.

Title: (insert title)

Author: (insert author)

Release Date: (insert date) [eBook #(insert ID number)]

Language: (insert language)

Character set encoding: (insert character encoding)

*** START OF THE PROJECT GUTENBERG EBOOK (insert title)***

 ---- the body of the text goes here ----

*** END OF THE PROJECT GUTENBERG EBOOK (insert title)***

***** This file should be named (insert file name) *****

(...)

However, few files satisfy this specification; for instance, none of the first 10 files posted on February 27, 2007 matched. In most cases, the first line lacked

n	number of distinct n -grams	error (%)
10	1.06×10^9	14
8	1.01×10^9	14
6	1.06×10^9	14
5	8.85×10^8	14
4	7.99×10^8	16
3	4.97×10^8	20
2	1.62×10^8	37
1	1.8×10^7	100

Table 3: Estimated number of distinct n -grams in the texts of the second PG DVD.

a comma and an occurrence of ‘THE’ had been replaced by ‘THIS’. Further, thousands of e-book files mention some of the old Internet hosts for PG, and these were not updated when the host changed: only two e-book files in the first DVD refer to www.gutenberg.org, and then not in the position required by the specification. Similarly, on the second DVD at least 13,000 (and probably more) of the roughly 20,000 files on the second DVD also do not match.

Besides the problem that the specification refers to items (such as Internet hosts) that change over time, the specification is not meant for automated processing. And the specification is not even complete: can we separate authors by new lines or just comas or other punctuation? How are editors handled?

The desired preambles and epilogues used in PG e-book files have changed several times over the years, and they may change again in future. This makes fully hand-crafted PG parsers [Atk04, Bur05, Gru06] an unsatisfactory solution. We feel the best way to obtain a robust solution is to use methods that automatically adjust to changes in data.

2.1 Domain Knowledge

Several properties of PG can help us choose an approach detect boilerplate. First, we know that all PG e-book files have preambles, although not all have epilogues. Second, we observe that the boilerplate text-flow is typically the same throughout the documents: sentences are split into lines at the same locations. This means that we can process frequent text-file lines, rather than parsing sentences from the text and looking for frequent sentences. We found no solution improvement and a notable running-time increase when we tried looking for frequent sentences. Third, we can set reasonable bounds on the maximum size of preamble and epilogue. Fourth, we can estimate the maximum number of times that a non-trivial line from the body of an e-book may be replicated.

We know there some textual replication between PG e-book files — but how much? Some e-books are compilations of an author’s work, whereas some of the items in the compilation are sometimes themselves e-books. Considering the two PG DVDs, there appears to be more replication in first PG DVD, where we find over 700 e-books present in both the initial and a second (corrected) version. Eighty e-books appear in a third version. *Frankenstein* is an extreme

case: the first DVD contains two editions of the book: one has five versions on the DVD whereas the other has three, for a total of 8 similar e-books. We estimate that nearly 10% of the first DVD’s e-book files are near-duplicates. However, we do not expect to see more than 10 files that are (near) copies, for any given e-book.

Finally, the properties of PG discourage us from considering frequent n -gram approaches, where an n -gram (of words) is a consecutive sequence of n words. To detect transitions in documents, n -gram statistics are sometimes used [SGWG06]. For example, the 5-gram “END OF THE PROJECT GUTENBERG” is likely to be frequent in the PG corpus. Computing the number of occurrences of each n -gram can be done efficiently with suffix arrays using the Nagao-Mori algorithm [NM94]. The size of the suffix array, which is several times larger than the original corpus, seems an unnecessary burden when one’s purpose is to remove boilerplate. Alternative data structures that maintain counts for each distinct n -gram are unlikely to be much better as we determined [LK06] there are nearly 10^9 distinct 5-grams on the second PG DVD by defining a word as text separated by white space (see Table 3).

3 Algorithm

Our solution identifies frequent lines of text in the first and last sections of each file. These frequent lines are recorded in a common data structure. Then, each file is processed and the prevalence of infrequent lines is used to detect a transition from a preamble to the main text, and one from the main text to an epilogue.

To motivate this approach, see Fig. 2. It shows the frequencies of the first 300 lines in each of 100 e-books randomly sampled from the first DVD. From it, we see files with long preambles (an older style) as well as those with short preambles (used in recent e-books).

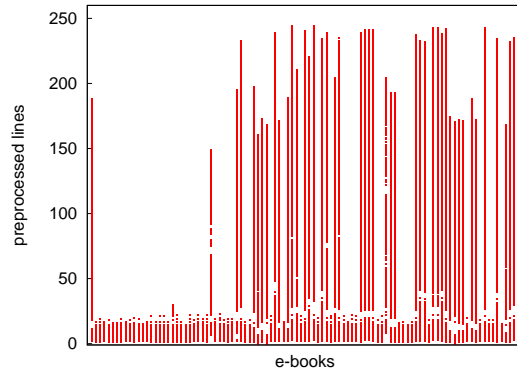


Figure 2: Pre-processed lines of frequency 100+ in the first DVD. The y -axis measures (pre-processed) line positions within an e-book file. There were 100 e-book files sampled from the first DVD.

3.1 Details

The core algorithm is shown in Algorithm 1. A line is frequent if it occurs more than K times in the corpus: we chose $K = 10$. We used the following ideas.

1. Preamble and epilogue lines are frequent. Exceptions include lines meant to contain the title of the work.
2. Lines not in the preamble or epilogue are infrequent with high probability, except for trivial lines such as “CHAPTER 1”.
3. Within most preambles or epilogues, there may be small gaps of infrequent text, but no large gaps.
4. The sizes of the preamble and epilogue can be bounded by p_{\max} and e_{\max} lines, respectively. (We use $p_{\max} = e_{\max} = 300$, after removing trivial lines.)

The algorithm always does some minor preprocessing of lines. It trims white space from the beginning and end of each line, and it replaces runs of ‘*’, ‘-’ or whitespace characters by ‘***’, ‘---’ or ‘ ’, respectively. It then omits as trivial those lines that are short (less than 30 characters) or have no alphabetic characters. These rules reflect the variety of typing discrepancies that seem likely when a human typist attempts manual duplication of boilerplate, or from “boundary errors” during cut-and-paste sessions. Omitting short lines should avoid problems from lines such as “CHAPTER ONE.”

3.2 Classification-Error Effects

Since Algorithm 1 cannot directly infer that a line belongs to the preamble or epilogue, it approximates this by distinguishing between frequent and infrequent lines. This test can yield a *false positive* when a non-boilerplate line occurs frequently, or a *false negative* when a boilerplate line occurs infrequently. The situation becomes worse if we choose inexact methods for determining line frequency.

Two types of errors may occur when trying to identify the preamble from line frequencies. If a sequence of false negatives occurs within the preamble, then we may cut the preamble short. If some false positives occur shortly after the preamble, then we may overestimate the size of the preamble. The analysis of the epilogue follows a similar pattern.

The effect of false negatives on the underestimation of the preamble is difficult to assess analytically, since occurrences are not independent of one another. For instance, an infrequent line about some unusual copyright situation is probably followed by another infrequent line that elaborates. Nevertheless, in the simplistic analytic model where false negatives occur with probability σ , the probability of encountering GAP_MAX false negatives is small and bounded by $L\sigma^{\text{GAP_MAX}} \leq 300\sigma^{\text{GAP_MAX}}$ where L is the length of the preamble in lines (known to be almost always smaller than 300). Even if σ is moderately large (25%), the probability $300\sigma^{\text{GAP_MAX}}$ will be very close to 0 for $\text{GAP_MAX} \approx 10$ (for example, $300 \times 0.25^{10} \approx 0.0003$). In

Algorithm 1 Algorithm to detect the end and start of boilerplate in a collection of documents. Lines that are too short or have no alphabetical characters are ignored.

Pass 1: identify frequent versus infrequent text

$p_{\max} \leftarrow 300, e_{\max} \leftarrow 300$

Scan first p_{\max} and last e_{\max} lines of each file.

for each line seen **do**

 pre-process line

 record in a frequent-lines data structure

end for

Pass 2: identify preambles and epilogues

for each file **do**

 constant GAP_MAX $\leftarrow 10$

 pre-process lines, skip till frequent line seen

 gap $\leftarrow 0$

while gap < GAP_MAX **do**

 read and pre-process line

if line is frequent **then**

 gap $\leftarrow 0$

else

 increment gap

end if

end while

 record that the preamble ends at the last-seen frequent line

 process the lines in the file in backwards order

 gap $\leftarrow 0$

while gap < GAP_MAX **do**

 read previous and pre-process line in file

if line is frequent **then**

 gap $\leftarrow 0$

else

 increment gap

end if

end while

 record that the epilogue starts at the most-recently-seen frequent line, or that no epilogue was seen if no frequent line was found

end for

fact, the expected number of lines before GAP_MAX false negatives are encountered is $\sum_{k=1}^{\text{GAP_MAX}} \sigma^{-k}$ (see Proposition 1) which is 1.4 million lines for GAP_MAX = 10 and $\sigma = 0.25$. Therefore, we might conclude that it is unlikely we will cut the preamble short by more than GAP_MAX lines. This is assessed experimentally in § 4.

Proposition 1 *If the probability of flipping a head is p , then the expected time before a consecutive sequence of n heads are observed is $\sum_{i=1}^n 1/p^i$.*

Proof. Let $H(k, n)$ be the expected time before we observe a sequence of n heads given that we just observed a sequence of k heads. We have that $H(k, n) = (1 - p)(1 + H(0, n)) + p(1 + H(k + 1, n)) = 1 + (1 - p)H(0, n) + pH(k + 1, n)$. Starting with $H(0, n) = p(1 + H(1, n)) + (1 - p)(H(0, n) + 1) = 1 + (1 - p)H(0, n) + pH(1, n)$ and recursively substituting the former equation, we get $H(0, n) = (1 - p^k)H(0, n) + 1 + p + \dots + p^{k-1} + p^k H(k, n)$, which we can prove by induction. Thus, because $H(n, n) = 0$, we have the desired result: $H(0, n) = \frac{1+p+\dots+p^{n-1}}{p^n}$. \square

However, regarding the risk of overestimation, it seems reasonable to assume the occurrences of false positives occur independently with probability p and an analytical approach is more conclusive. Indeed, in the body, one line’s being frequent (such as “CONTENTS OF THE SECOND VOLUME.”) would rarely imply that neighbouring lines are frequent. For simplicity, we assume that there are no false negatives — false negatives only help the situation — and we focus on preambles. Epilogues would be similar. Let p denote the probability of a false positive. We see that the last line of the identified preamble will be GAP_MAX (pre-processed) lines **before** the point when a consecutive sequence of GAP_MAX negatives has been seen. Using Proposition 1, we determine that the expected number of misclassified lines following the preamble is $\sum_{k=1}^{\text{GAP_MAX}} (1 - p)^{-k} - \text{GAP_MAX}$.

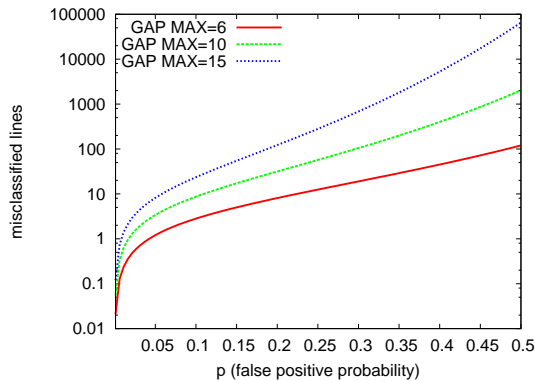


Figure 3: Expected number of non-preamble lines misclassified, given false-positive probability p . We assume false positives are independent and show results on a logarithmic y axis.

Figure 3 shows the effect of various values of p on this function. With $\text{MAX_GAP} = 10$, we want $p \leq 20\%$.

3.3 Data Structures

The algorithm’s first pass builds a data structure to identify the frequent lines in the corpus. Several data structures are possible, depending whether we require exact results and how much memory we can use. One approach that we do *not* consider in detail is taking a random sample of the data. If the frequent-item

threshold is low (say $K = 5$), too small a sample will lead to many new false negatives. However, when K is large, sampling might be used with any of the techniques below.

Although we assume that only 600 ($p_{\max} + e_{\max}$) lines are processed per PG e-book file, there may be similar applications where this assumption cannot be made and the entire file must be processed. The impact of removing the assumption on the desired data structure should be considered.

3.3.1 Exact Counts Using Internal Memory

For exact results, we could build a hash table that maps each line seen to an occurrence counter. In Java, the Collections library provides `HashMap<String,Integer>`. This has the disadvantage of consuming much memory. Of the 600 pre-processed lines we take from each file, we estimate about half are unique, non-preamble/epilogue lines, because a given file normally has a large preamble or a large epilogue, but not both. Within the first and last 300 pre-processed lines of the first DVD's files, we see only 3.4 million distinct lines. A routine estimation (details omitted) says we need about 700 MiB for our data structure. If the data structure indeed fits, it will tie up most of our main memory (see Table 2).

3.3.2 Exact Counts Using External Memory

To know exactly which lines occur frequently, if we have inadequate main memory, an external-memory solution is to sort the lines. Then a pass over the sorted data can record the frequent lines, presumably in main memory. If we build a file `F` containing just the first and last 300 non-trivial pre-processed lines of each file, the following GNU/Linux pipeline prints a list of under 3,000 frequent lines (occurring 10 times or more) in less than 100 s on our somewhat old server:

```
sort F -S 512M | uniq -c | egrep -v '^ *[1-9] '
```

Part of the result (frequency counts and the lines) is shown in Fig. 4. A histogram for the data (see Fig. 5(a)) shows that the distribution is very skewed: out of 3.4 million distinct lines, 2.6 million lines appear only once and 0.7 million lines appear twice, with less than 100,000 lines appearing more than 2 times and fewer than 3,000 appearing 10 or more times. We see e-book-specific text occurring with some surprising frequency due to cut-and-paste errors (we verified that 19 files that were *not* `1rbnh10.txt`, mistakenly claimed that this should be their name). We also see boilerplate shifts: (*eBook* and *EBook* versus *etxt*, *net* versus *gross* and *Project* versus *Foundation*). Only 53 files have the *twenty percent* spelled out (see Fig. 4), illustrating that rare boilerplate *does* occur and showing how false positives/negatives may arise.

3.3.3 Checksumming

For nearly exact results, we can hash lines to large integers, assuming that commonly used hashing algorithms are unlikely to generate many collisions. We chose the standard CRC-64 checksum, and a routine calculation [Wik07] shows that with a 64-bit hash, we can expect to hash roughly $2^{64/2}$ distinct

```

68 ***The Project Gutenberg's Etext of Shakespeare's First Folio***
1034 ***These EBooks Were Prepared By Thousands of Volunteers***
1415 ***These Etexts Are Prepared By Thousands of Volunteers!***
126 ***These Etexts Were Prepared By Thousands of Volunteers!***
5058 ***These eBooks Were Prepared By Thousands of Volunteers!***
20 ***This file should be named 1rbnh10.txt or 1rbnh10.zip***
128 (2) Pay a royalty to the Foundation of 20% of the gross
54 (2) Pay a royalty to the Project of 20% of the net
53 [3] Pay a trademark license fee of 20% (twenty percent) of the
8061 [3] Pay a trademark license fee to the Foundation of 20% of the

```

Figure 4: Some of the approximately 3,000 frequent sorted lines in the first DVD.

lines before getting a collision. With hashing, each line is represented using 8 bytes, reducing memory usage tenfold. Even considering the other overheads of the data structure, Java's `HashMap<Long,Integer>`, it seems clear that the tops and bottoms of all PG files can be processed comfortably within our 1 GiB limit.

If we hold constant the threshold K beyond which an item is considered frequent, checksumming does not increase the rate of false negatives. It may increase the rate of false positives, when the sum of several colliding lines' frequencies exceeds K . This effect should be negligible for CRC-64.

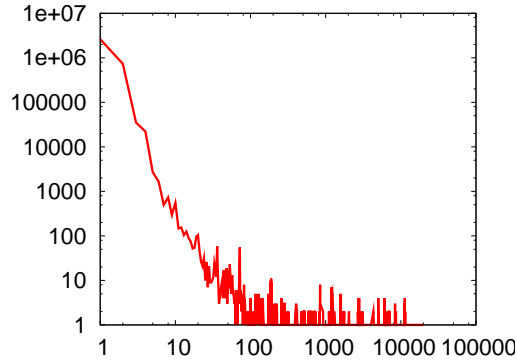
Solutions that use even less memory may be desirable, when all of a file must be processed. For instance, suppose that a block of boilerplate could appear anywhere in a file.

3.3.4 Hashing to Millions of Counters

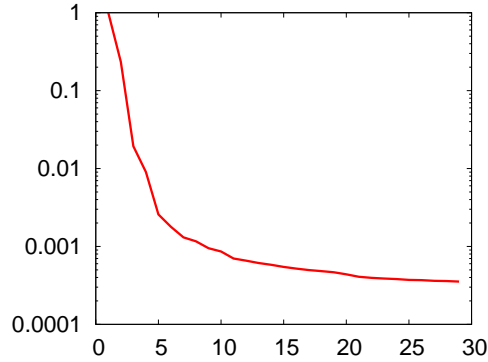
To use even less memory than CRC-64 hashing, one solution is to use a smaller hash (e.g., a 30-bit hash) and accept some collisions. Once the range of the hash function is small enough, it can directly index into an array of counters, rather than requiring a lookup in a secondary structure mapping checksums to counters. This could lead to speed or space advantages: for the entire PG corpus and with $K = 10$, we could use 2^{30} 8-bit counters for a total of 1 GiB. With larger K ($K > 255$), approximate counting [Mor78] can trade count accuracy for the ability to count to 2^{28} .

When using this data structure with Algorithm 1, frequent lines will be correctly recognized as such, but we can expect to increase the rate of false positives for two reasons. First, we get a false positive from an infrequent line that shares the same counter with a frequent line. Second, we get false positives from a collection of infrequent lines that share the same counter and jointly have too many occurrences.

In our experiments on the first PG DVD, we process only files' tops and bottoms, and we use a 23-bit hash with the 3.4 million distinct lines. Assume that hashing distributes lines uniformly and independently across the counters. Then the probability that a randomly selected infrequent line will share a counter with



(a) Number of lines appearing a certain number of times. The scales are logarithmic.



(b) Probability to pick a line having at least the given number of occurrences.

Figure 5: Line occurrence statistics in the beginning and end (300 non-trivial lines) of text documents on the second Gutenberg DVD.

one of the ≈ 3000 frequent lines is estimated as $\approx 3000 \times 2^{-23} = 3.6 \times 10^{-4}$. These few additional false positives should not be harmful.

It is more difficult to assess the additional false positives arising when a collection of infrequent lines share a counter and together have an aggregate frequency exceeding the frequent-item threshold, K . We can approach this problem experimentally. Since we do not precisely know the boilerplate locations for the entire first DVD, we plot the number of lines that falsely appear frequent due to hashing, divided by the number of lines processed. This is affected by K (we show several values of K) and by the number of counters used (x -axis). Fig. 6 shows these experimental results and two theoretical bounds we shall derive.

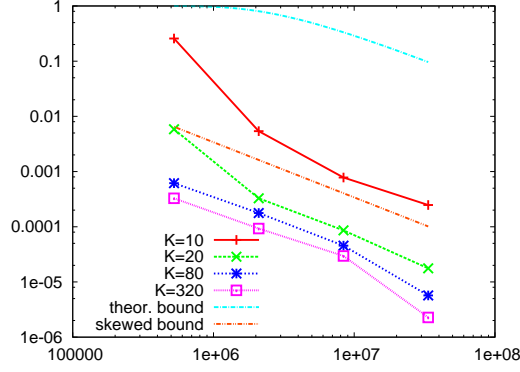


Figure 6: Lines falsely assessed as frequent (as a proportion of the total assessments done) versus number of counters, c . Several different frequent-line thresholds (K) are shown, as well as the theoretical bound $1 - e^{-\frac{n-1}{c}}$ where n is the number of distinct lines. The skewed distribution bound is $p^{\frac{n-1}{c}}$ with $p = 1/1000$.

Consider the probability, p_{FP} , that a line j picked at random among all lines in a file is a false positive. Let X_1 be the frequency of our chosen line. Naturally, more frequent lines are more likely to be picked. By definition, if the line is frequent, it cannot be a false positive. Thus $p_{\text{FP}} = P(X_1 \leq K)P(\text{line } j \text{ is a false positive} | X_1 \leq K)$.

Assuming that the hashing is uniform and independent, then the number N of distinct lines hashed to a certain value follows a binomial distribution. We need to pick a line j at random: for $k \geq 1$, the probability that k distinct lines are hashed to the same hash value is $P(N = k) = B(n-1, k-1, \frac{1}{c}) = \binom{n-1}{k-1} (\frac{1}{c})^{k-1} (1 - \frac{1}{c})^{n-k}$ or, alternatively, $P(N = k) = \frac{kc}{n} B(n, k, \frac{1}{c}) = \frac{kc}{n} \binom{n}{k} (\frac{1}{c})^k (1 - \frac{1}{c})^{n-k}$. Because n is large, we can approximate the binomial distribution with a Poisson distribution ($e^{-\frac{n-1}{c}} (\frac{n-1}{c})^{k-1} / (k-1)!$). The probability that we have a false positive when $X_1 \leq K$ is $P(\text{line } j \text{ is a false positive} | X_1 \leq K) = P(X_1 + X_2 > K | X_1 \leq K)P(N = 2) + P(X_1 + X_2 + X_3 > K | X_1 \leq K)P(N = 3) + \dots$ where X_i denotes the count of one of the various distinct lines with the same hash as line j . Moreover, we can bound how many distinct lines can be hashed together. Indeed, under the assumption that $n \leq c$, because $P(N = k) \approx e^{-\frac{n-1}{c}} (\frac{n-1}{c})^{k-1} / (k-1)! \leq 1/(k-1)!$, we have that $P(N \geq 9) \lesssim \sum_{k=9}^{\infty} 1/(k-1)! \approx 2 \times 10^{-5}$ and $P(N \geq 6) \lesssim \sum_{k=5}^{\infty} 1/(k-1)! \approx 0.05$.

The exact probability of detecting a false positive naturally depends on the value of the counter X_1 , but we can at least bound the probability of observing a false positive as follows. First, a false positive requires one (or more) lines hashed together with the current line. Thus, a crude upper bound is $p_{\text{FP}} \leq P(\text{line } j \text{ is a false positive} | X_1 \leq K) \leq P(N \geq 2) = 1 - P(N = 1) = 1 - (n-1)!(1 - 1/c)^{n-1} \approx 1 - e^{-\frac{n-1}{c}}$.

Finer bounds are possible by using Chebyshev’s inequality or exact knowledge of the distribution of the X values. If we assume that the distribution of the X values is very skewed, X is larger than K with a very small probability p and small compared to K otherwise, then we can also assume that $P(\sum_{i=1}^k X_i > K | X_1 \leq K) \lesssim (k-1)p$ for $k < 10$. Then, the probability of a false positive when $X_1 \leq K$ is $P(X_1 + X_2 > K | X_1 \leq K)P(N = 2) + P(X_1 + X_2 + X_3 > K | X_1 \leq K)P(N = 3) + \dots \lesssim \sum_{k=2}^{\infty} (k-1)pe^{-\frac{n-1}{c}} \left(\frac{n-1}{c}\right)^{k-1} / (k-1)! = p\frac{n-1}{c}$. (The expected value of the Poisson distribution is $\sum_{k=0}^{\infty} ke^{-\lambda}\lambda^k/k! = \lambda$.) Hence, $p_{\text{FP}} \leq p\frac{n-1}{c}$ and it follows that if $P(\sum_{i=1}^k X_i > K | X_1 \leq K) \lesssim (k-1)p$ for $k < 10$, the probability of a false positive is no more than p . We estimate from Fig. 5(b) that the Gutenberg line data set has such a distribution with $p \approx 1/1000$ for $K \approx 100$. In Fig. 6 this bound, $p\frac{n-1}{c}$, is compared against some experimental results.

3.3.5 Tracking Hot Items

Many algorithms have been developed for detecting “frequent items” in streams, and we might use one with Algorithm 1. In such a context, we are not interested in counting how many times a given item occur, we only want to retrieve frequent items. Cormode and Muthukrishnan survey some of them [CM05b]. Given enough memory, Pass 1 of our algorithm can be done with one pass through the corpus. Yet if we seek to reduce memory usage, then we must either give up the ability to capture all frequent items (create false negatives), or the ability to capture only the frequent items (create false positives), or several passes are required.

Typically, in one pass, these algorithms deliver a set that contains all frequent items (and some infrequent items). A particularly simple and fast deterministic method, *Generalized Majority* (GM), has been developed independently by several authors [DLM02, KSP03, MG82].

Algorithm 2 GM Algorithm [DLM02, KSP03, MG82]: at the end of the run, all elements occurring at least $n/(c+1)$ times are monitored by a counter.

Input: a stream of length n
initialize all c counters to zero
for each element in the stream **do**
 if the element is not currently monitored by a counter and a counter is zero
 then
 set this counter to monitor the item
 end if
 if the element is monitored **then**
 increment the counter
 else
 decrement all counters
 end if
end for

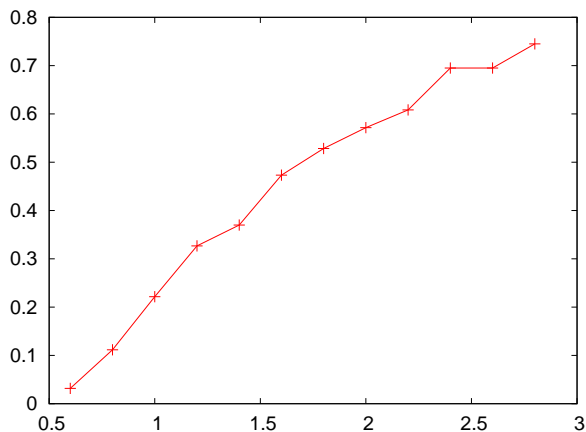


Figure 7: Efficiency of the GM algorithm for various Zipfian distributions. The item of rank r has frequency proportional to $1/r^x$.

GM uses c counters, where $c \geq 1/f - 1$ and f is the minimum (relative) frequency of a frequent item; in the special case where $f = 1/2$, a single counter is sufficient (see Algorithm 2). GM can be implemented to run in $O(1)$ time per element [DLM02]. The implementation uses doubly linked lists of doubly linked lists, as well as auxiliary data structures mapping counted items to their counters. Hence it may use significant memory per counter.

Probabilistic variants of GM have been proposed [DLM02]. However, in the case where the distribution is very skewed, the algorithm already provides a good approximation of the frequent items: it suffices to keep only the items with the largest count values. We believe this observation is novel, though there is related work [CM05a]. To evaluate its accuracy, we generated generalized Zipfian data sets ($n \approx 100,000$) containing 1,000 distinct items: the frequency of the rank r item is proportional to $1/r^x$. We then apply the GM algorithm and find the largest value of k such that the top- k -items query is exact.

Let this value of k divided by the number of counters c be called the *efficiency* of the algorithm. For each value of x , we repeat the experiment 30 times, with different random ordering of the items, and compute the average efficiency. The result is presented in Fig. 7 for $c = 30$; we determined empirically that the efficiency is not sensitive to the number of counters. Clearly, for highly skewed distributions, the efficiency can be very close to 100%.

Consider using GM to detect frequent lines in Algorithm 1. Scanning only the tops and bottoms of files, we see 3×10^6 lines, and suppose we choose $K = 100$. To guarantee a set of items that includes all such frequent lines we need at least 3×10^4 counters ($3 \times 10^4 \times 100 \geq 3 \times 10^6$). Since we know that this is much larger than the number of frequent items, we will have introduced many false positives. However, by the previous argument and assuming a very skewed distribution, we can select the items with a relatively large count and expect to

have few false positives. We will review the applicability of GM experimentally later on.

3.4 Heuristic Improvements

A large majority of PG e-books can have their preambles and epilogues detected by a few heuristic tricks. However, there are many exceptions where the tricks fail, and our experience is that they cannot replace the frequent-line approach without being significantly more complex and constantly updated. Yet, heuristics can improve processing based on frequent lines.

The heuristic rules we consider can be expressed as Java regular expressions.

- If a line near the beginning of the file matches the following, it is part of the preamble.

```
[\\s*]*\\*[\\s]? (START\\sOF\\s(THE|THIS)\\sPROJECT  
\\sGUTENBERG|END[\\s*]THE\\sSMALL\\sPRINT!) .*
```

- If a line near the end of the file matches the following, it is part of the epilogue.

```
This|THIS|this|Is|IS|is|The|THE|the|Of|OF  
|[*\\s]|of)*(End|END|end)(\\s|Of|OF|of|The|THE  
|the|This|THIS|this)*(Project\\s+Gutenberg|  
PROJECT\\s+GUTENBERG) .*
```

- If a line begins with ETEXT and is near the end of the file, it is part of the epilogue.

4 Experimental Results

We implemented Algorithm 1 and the data structures discussed in § 3.3 in Java 1.5 (using Sun’s JDK 1.5.0) and tested them on a older machine with Pentium 3 Xeon processors (700 MHz with 2 MiB cache) and 2 GiB of main memory. The OS kernel was Linux 2.6.18, and the disk system had three 10 kRPM Ultra SCSI disks. We copied the contents of the first PG DVD onto the hard disk and did some simple preparations, primarily unzipping all files and removing README files.

We chose 100 e-book files randomly out of the approximately 11,000 and the boilerplate boundaries were determined exactly by the authors. The algorithm then processed all files ($\approx 11,000$), and then its accuracy was assessed by checking the sample. The GM data structure used $c = 10^5$ counters, whereas the hashing algorithm used $c = 2^{23}$ counters. (Since GM stores lines and uses complicated auxiliary data structures, the actual memory used by GM and hashing was much closer than comparing c values would indicate.) The threshold beyond which a line is considered frequent is $K = 10$ for all data structures except for GM where we used a counter value² of 5.

Results were compared with and without the use of the supplementary heuristics from § 3.4.

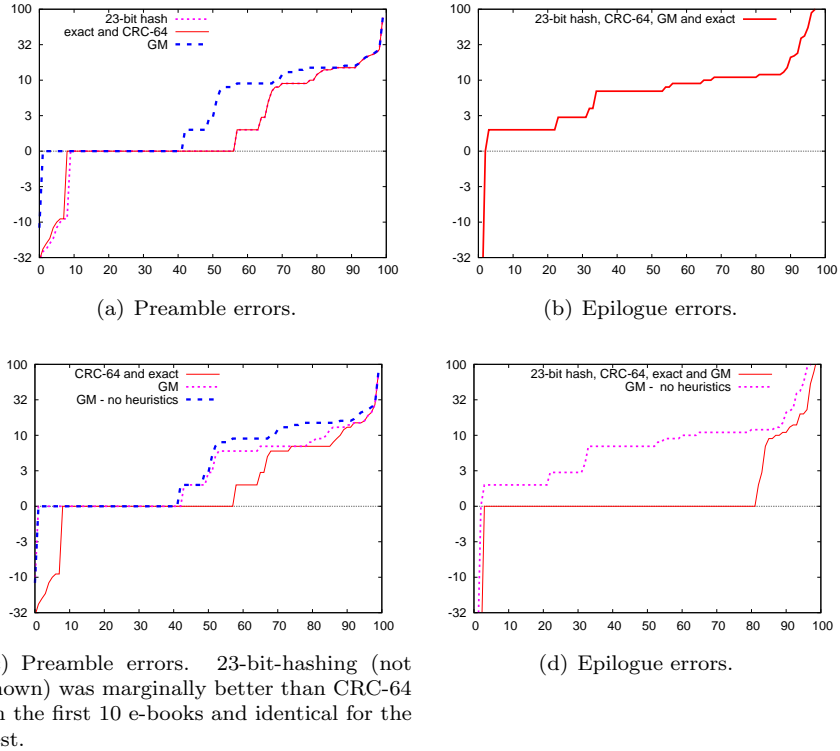


Figure 8: Preamble/epilogue errors (negative quantities mean that too many lines were removed; positive quantities mean insufficient lines were removed). In 8(c) and 8(d) heuristics were used along with the frequent-line algorithm (with the exact and GM data structures) whereas heuristics were not used in 8(a) and 8(b). For comparison, GM is also shown without heuristics.

4.1 Errors

Figures 8(a) and 8(b) show the number of lines missed by the preamble-removal or epilogue-removal process, respectively, for each of the 100 files where we sorted the files by the number of lines missed. Errors (number of lines) are measured in actual e-book lines, including trivial lines that pre-processing had discarded.

In these experiments we did **not** use the regular-expression-based heuristics. Looking at epilogues, we see the choice of data structure did not have much effect on accuracy; problems with false positives or negatives must come from the data itself. For preambles, we see that the GM approach had moderately higher errors in about 30% of the cases. However, this always involved 10 or fewer lines.

²GM decrements, so this does not mean $K = 5$.

Figures 8(c) and 8(d) show how the errors changed when we **did** use the regular-expression-based heuristics. Comparing results on preamble detection, we see that the heuristics were somewhat helpful, but GM still had difficulties compared to using exact counts in about 30% of the cases.

Comparing results on epilogue detection, we see that heuristics reduce our error to 0 in about 75% of cases (whereas in these cases, GM without heuristics would have had an error of 1–10 lines).

4.2 Run Times

Our Java implementation of Algorithm 1 processed the DVD’s files in 20-30 minutes, for each of the data structures. The bottleneck is our unoptimized implementation of line pre-processing; this trivial task obscures the differences between the data structures. Yet, it seems clear that with sufficient implementation effort this preprocessing bottleneck could be removed. Then, the speed differences would arise from the choice of frequent-lines data structure, and the differences between these data structures will be most pronounced during the construction of the structure (the first pass); during the second pass, the classification of lines typically involves a similar $O(1)$ frequency look up per line.

Therefore, we prepared a single file containing pre-processed tops and bottoms of the files on the first PG DVD. We then used this file to construct each of the data structures, subtracting the time (approximate 20 s) it took to read the file. Experiments considered a range of values for c , the number of counters used. For each data point, ten trials were made and their average is shown in Fig. 9. Exact and CRC-64 always use as many counters as there are distinct lines whereas the 23-bit hash always allocates the same number of counters; times for these data structures should not vary with c .

We see that 23-bit hashing was the fastest approach, requiring about 55 s. For small c , GM is nearly as fast, but it slowed as c increases to the number of distinct items (3.4 million), at which point its speed resembles the exact structure. This is not surprising; GM uses a Java `HashMap` to associate each counted line to its counter. The “exact” implementation was slowest, and it also uses a `HashMap` for the same purpose, although “exact” maps to an `Integer` rather than GM’s more complicated data structure. When fewer counters are used, GM maintains a smaller `HashMap` and, despite having to do additional book-keeping beyond “exact”, the speed benefit of the smaller `HashMap` outweighs the cost of book-keeping. When CRC-64 is used, these values are also stored in a `HashMap`, so the speed advantage enjoyed by CRC-64 presumably arises from its more economical use of memory. If GM stored CRC values rather than strings, its performance should match CRC-64 when $c \geq 3.4$ million.

Experiments were limited to 2^{24} counters because GM made our system run out of memory when 2^{26} counters were used (we limited the JVM to 1.8 GiB). While this might be due to an inefficient implementation, we feel that only our 23-bit hashing implementation (which uses space-efficient arrays of basic types)

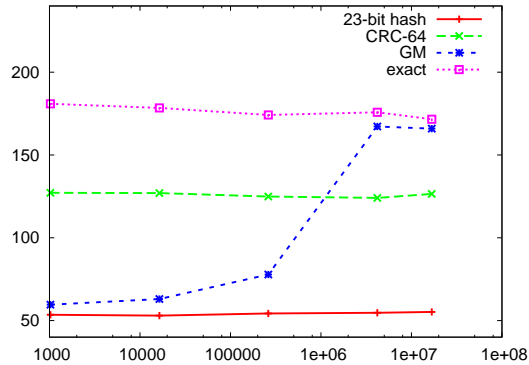


Figure 9: Wall-clock times (s) to build the frequent-lines structures vs. the number of counters, c .

would successfully scale for much larger corpora. Of course, using external-memory techniques is also a viable solution. Recall that GNU/Linux shell utilities, presumably highly optimized, could sort and build the list of frequent lines in under 100s.

4.3 Comparison to GutenMark

Of those software tools that reformat PG e-books, it appears only GutenMark [Bur05] formally attempts to detect the preamble, so it can be stripped. We used its most recent production release, dated 2002, when PG e-books did not have a long epilogue. Thus we can only test it on preamble detection.

GutenMark attempts to bypass all prefatory material, whether inserted by PG or part of the original text. To do so, it tries to detect the body of the text, looking for markers such as “Chapter I.” Unlike our tool, it thus tries to omit tables of contents, etc.

With GutenMark, the preamble is stripped only in an output format (we use HTML) and the stripping is accompanied with various reformatting heuristics: all-capitalized text is transformed in italics, punctuation is transformed into HTML entities, and headers are identified and marked using h1 elements in HTML.

To determine where GutenMark infers the preamble, we use the main header tags (h1 elements in HTML) that it generates. Usually, the first header is “Prefatory Materials” and the second begins the body of the e-book. We then have to map this back to corresponding lines in the original text file, which may look quite different due to reformatting.

Processing e-book files with GutenMark is slow compared to our implementations of Algorithm 1, but it is unfair to draw conclusions from this. GutenMark was not intended to process a large corpus, and it processes all of the file. A heuristic-based approach similar to GutenMark could probably be implemented

so that it would run faster than our approach: it has no frequent-line data structure to maintain and can probably process the corpus in a single pass. However, is it accurate?

Figure 10 shows the errors obtained when we inferred where GutenMark detected preambles. In one case, *Diary of Samuel Pepys, October 1666*, we see an error of more than 1000 lines. Apparently the diary format used did not have headings GutenMark could detect.

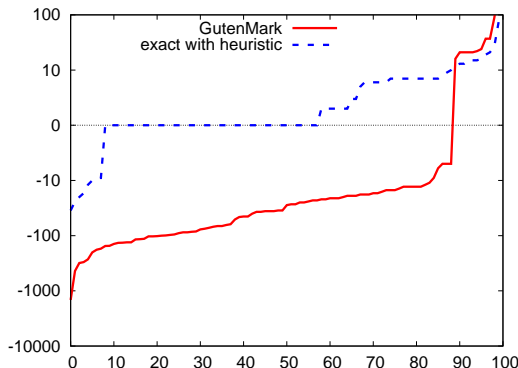


Figure 10: Preamble errors for GutenMark.

Despite several other large errors, in many cases the GutenMark approach worked reasonably well. Its erratic behaviour illustrates the risk of heuristics rules inferred manually from an out-of-date corpus version.

5 Conclusion

The PG Project is a good example of a large, poorly structured data set. Nevertheless, it is evidently proving useful since thousands of volunteers contribute to the project every year.

Detecting the PG-specific preambles and epilogues is maybe surprisingly difficult. There are instances where a human without knowledge of English probably could not accurately determine where the preamble ends. Nevertheless, our approach based on line frequency can approximately (within 10%) detect the boilerplate in more than 90% of the documents (see Fig. 8).

Line frequency follows a very skewed distribution and thus, as we have demonstrated, hashing to small number of bits will not lead to a large number of lines falsely reported as frequent. Indeed, using 23-bit line hashing, we can approximately find the frequent lines, with an accuracy sufficient so that preamble/epilogue detection is not noticeably affected. Simple rule-based heuristic can improve accuracy in some cases, as observed with epilogues.

Future work should include automatic detection of the remaining cases, which require human intervention. In general, this will be difficult. Yet a few simple sanity tests are possible; for instance, seeing ‘Gutenberg’ in the body of an e-book is typically a sign of trouble.

All that is required for our approach to scale up is to detect frequent lines efficiently. Because the distribution of line frequency is very skewed, highly efficient algorithms are possible, such as the hashing and GM algorithms, without sacrificing accuracy significantly.

Training accuracy could be improved by including only one copy of each e-book, or forming separate frequent-lines data structures for preambles and epilogues. Much replication can be removed by using PG catalogue metadata that is available from the Project. We did not use it; thus, our results apply to similar corpora lacking catalogue metadata.

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