FUSE: A Reproducible, Extendable, Internet-scale Corpus of Spreadsheets

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***Abstract*—Spreadsheets are perhaps the most ubiquitous form of end-user programming software. This paper describes a corpus, called FUSE, containing 2,127,284 URLs that return spreadsheets (and their HTTP server responses), and 249,376 unique spreadsheets, contained within a public web archive of over 26.83 billion pages. Obtained using nearly 60,000 hours of computation, the resulting corpus exhibits several useful properties over prior spreadsheet corpora, including reproducibility and extendability. Our corpus is unencumbered by any license agreements, available to all, and intended for wide usage by end-user software engineering researchers. In this paper, we detail the data and the spreadsheet extraction process, describe the data schema, and discuss the trade-offs of FUSE with other corpora.**

I. INTRODUCTION

End-user programmers today constitute a broad class of users, including teachers, accountants, administrators, managers, research scientists, and even children [1]. Although these users are typically not professional software developers, their roles routinely involve computational tasks that, in many ways, are similar to those of developers — not just in activity, but also in their underlying cognitive demands on users [2].

Perhaps the most ubiquitous form [3] of end-user programming software are *spreadsheets*, a table-oriented visual interface that serves as the underlying model for the users' applications [4]. *Cells* within these tables are augmented with computation, such as expressions, functions and macros [4]. This interplay between presentation and computation within the spreadsheet environment has garnered significant interest from the software engineering research community [5]. Researchers have adopted techniques and approaches to studying errors [6], code smells [7], and refactoring in spreadsheets [8], similar to traditional programming environments.

To better understand end-user activities and design tools to assist end-users, researchers have responded by curating spreadsheet corpora to support spreadsheet studies [9], [10], [11]. This paper presents one such spreadsheet corpus, called FUSE, extracted from the over 26.83 billion web pages in the Common Crawl index. We believe that FUSE offers several useful traits not found in prior corpora; for example, FUSE is obtained in such a way that researchers can independently reproduce an identical corpus from source materials.

The contributions of this paper are two related datasets, which together constitute the FUSE spreadsheet corpus[1]:

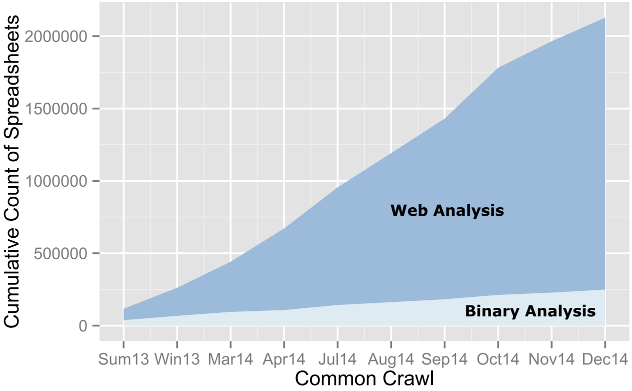


Fig. 1. Cumulative count of spreadsheets obtained with each additional crawl. Web Analysis contains all URLs and associated HTTP server responses, while Binary Analysis contains the actual spreadsheets for a subset of Web Analysis, archived within Common Crawl.

- A *Web Analysis* dataset of 2,127,284 URLs that return spreadsheet content, along with the full HTTP web server response, formatted as JSON records. This dataset is obtained by filtering through 26.83 billion HTTP responses within the Common Crawl archive.
- A *Binary Analysis* dataset of 249,376 spreadsheets, extracted from the 1.9 PB of raw data within the Common Crawl archive. For each spreadsheet, we provide JSON metadata containing our analysis, which includes NLP token extraction and spreadsheet metrics.

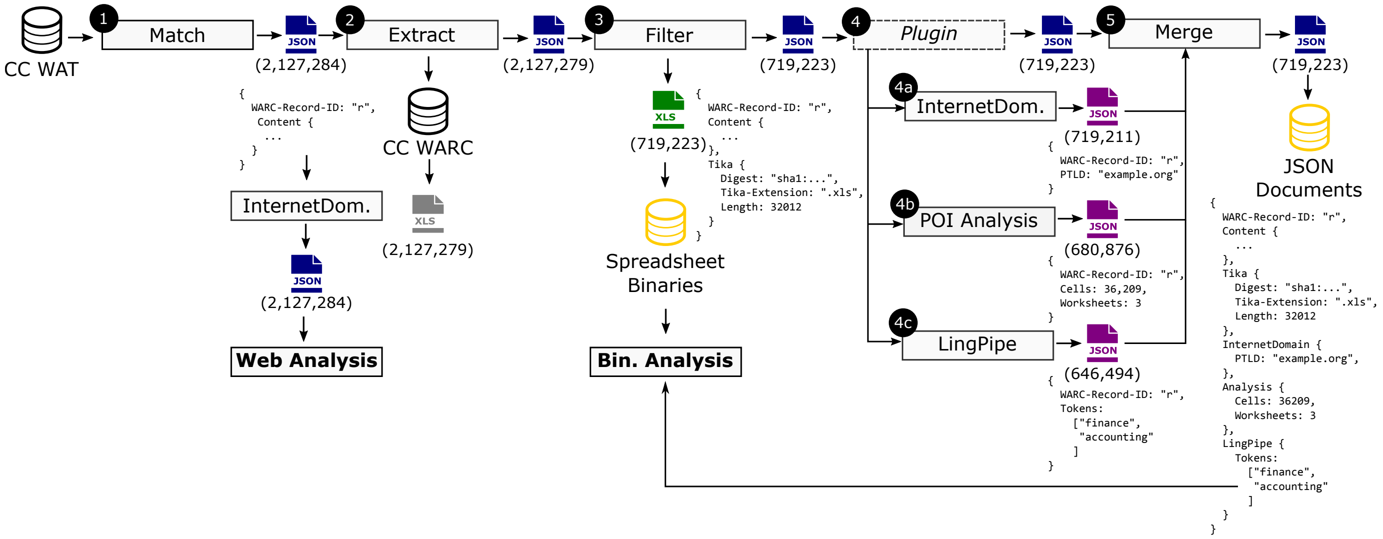
II. DESCRIPTION OF DATA

The Common Crawl[2] non-profit organization is dedicated to providing a copy of the Internet, and democratizing the web crawl data so that it is accessible to everyone. Of specific interest to us is that the corpus contains not only the HTTP responses of web pages, but also the raw content of each of these resources, including binaries. It is from these monthly Web crawls that we extract and make available spreadsheets and corresponding metadata, augmented with our analysis, and tailored to researchers.

The result, FUSE, is characterized through two, hierarchical datasets (Figure 1): a Web Analysis dataset, and a Binary

[1] The corpus metadata, spreadsheets, tools, and other documentation can be obtained at http://go.barik.net/fuse.

[2] http://commoncrawl.org



```
{
  WARC-Record-ID: "r",
   Content {
     ...
  }
}
```

```
{
  WARC-Record-ID: "r",
  Content {
    ...
  },
  Tika {
    Digest: "sha1:...",
    Tika-Extension: ".xls",
    Length: 32012
  }
}
```

```
{
  WARC-Record-ID: "r",
  PTLD: "example.org"
}
```

```
{
  WARC-Record-ID: "r",
  Cells: 36,209,
  Worksheets: 3
}
```

```
{
  WARC-Record-ID: "r",
  Tokens:
    ["finance",
     "accounting"
    ]
}
```

```
{
  WARC-Record-ID: "r",
  Content {
    ...
  },
  Tika {
    Digest: "sha1:...",
    Tika-Extension: ".xls",
    Length: 32012
  },
  InternetDomain {
    PTLD: "example.org",
  },
  Analysis {
    Cells: 36209,
    Worksheets: 3
  },
  LingPipe {
    Tokens:
      ["finance",
       "accounting"
      ]
  }
}
```

Fig. 2. The MapReduce pipeline for extracting spreadsheets and associated spreadsheet analysis metadata from Common Crawl.

Analysis dataset.

Web Analysis: This dataset contains 2,127,284 spreadsheet-related URLs and HTTP responses. 292,043 of these responses point to a unique URL, and the top domain is `.org` (29.5%), followed by `.gov` (27.7%). The analysis contains 6,316 distinct domain names. Unfortunately, relying solely on Web Analysis for spreadsheets will not result in a reproducible corpus, as the Internet is always in flux.

Binary Analysis: To address the limitations of Web Analysis, the Binary Analysis dataset contains 249,376 unique spreadsheets, extracted directly from the raw data contained within Common Crawl archives, rather than the Internet. Since each monthly Common Crawl archive is a permanent snapshot in time, Binary Analysis is always reproducible.

Analyzing these spreadsheets, we discovered that `IF` is the most frequently used function, found in 17.8% of all formula cells, giving evidence that spreadsheets require non-trivial computation. We also discovered that `=SUM(R[[-3]C:R[-1]C)` is the most common formula, in which a cell is the sum of the three cells to its left, and that it appears in 1,322 spreadsheets. In contrast with domain specific corpora, such as Enron, our general spreadsheet corpora has fewer formulas. Interestingly, only 7.00% of our spreadsheets contain any formula, as opposed to 59.4% of Enron spreadsheets, which is consistent with anecdotal findings of the Excel team.[3]

This analysis hierarchy has several properties desirable to researchers, the first of which is reproducibility. In Web Analysis, an independent researcher should always obtain the same set of spreadsheet-related URLs, provided they use the same spreadsheet detection heuristic. Because the spreadsheets from Binary Analysis are obtained from content embedded in the Common Crawl corpus, they are reproducible resources. A second property of our corpus is that it is open to extension, without sacrificing reproducibility. When Common Crawl releases a new dataset, these crawls can be incrementally incorporated into FUSE. A third useful property of our corpus is related not to the data itself, but to its broader ecosystem: FUSE is unencumbered by any licensing requirements, available to all, and includes a scalable, open source toolchain.

III. METHODOLOGY

The Common Crawl is available as a public dataset on Amazon, and crawl data is stored on Simple Storage Service (S3) as a set of WARC (Web ARChive) files, which store the raw crawl data, and a corresponding WAT file, which stores the web crawler metadata for the given WARC file. Essentially, each WAT file contains JSON-formatted records that act as an index into the WARC raw data. That is, each record contains a globally unique identifier, which we call a `WARC-Record-ID`, and a reference to a WARC filename, offset, and length. S3 supports downloading segments of files in this way.

We examined crawl data from the period of Summer 2013 through December 2014, which consisted of 26.83 billion web pages, compressed as 423.8 TB (1.9 PB uncompressed). To support parallelization, this data is split into 481,427 segments, such that different machines can independently process a segment. Extracting such a corpus from a single desktop machine is computationally intractable, and thus we extracted the spreadsheets using the Amazon Elastic MapReduce service.

A. Hadoop MapReduce Pipeline

Figure 2 illustrates our MapReduce framework, which consists of five stages that comprise a pipeline. For each stage in the framework, we compute the cost in terms of normalized instance hours. The total hours correspond to the approximate

[3] Joel Spolsky writes, "Everybody thought of Excel as a financial modeling application, [but] we visited dozens of Excel customers, and did not see anyone using Excel to actually perform what you would call 'calculations.' Almost all of them were using Excel because it was a convenient way to create a table." — http://www.joelonsoftware.com/items/2012/01/06.html

amount of time that it would take for a 1 vCPU, 1.7 GiB machine to complete the task — in other words, roughly comparable to a single end-user desktop machine. Although researchers do not need to use our pipeline to reproduce our results, our framework already contains the necessary MapReduce scaffolding, such as task scheduling code, as well as Java libraries, to support distributed analysis.

1) Match: This stage required that we traverse every JSON-formatted URL and HTTP response in the 481,427 WAT segments and match spreadsheet-related records. First, we checked if the HTTP response payload `Content-Type` field corresponded to one of seven spreadsheet MIME types as supported by Microsoft Excel.[4] However, some records contained a generic binary `Content-Type` of `application/octet-stream`, in which case `Content-Disposition` was checked via a file pattern matching "`.xls*`". If either of these conditions were true, we saved the record using the `WARC-Record-ID` as the key. This is a heuristic process because cannot know for sure that a record is actually a spreadsheet until we inspect the extracted file. This key identified the file throughout the pipeline. After filtering through some 26.83 billion records, we identified 2,127,284 candidate spreadsheets. This stage, the most computationally expensive in the pipeline, required about 55,000 normalized instance hours to process.

2) Extract: The extract stage loaded the 2,127,284 candidate spreadsheets records. Using the `Filename`, `Offset`, and `Deflate-Length` fields of the record, the corresponding WAT record was extracted into memory. The WARC record was then stripped of its header information (e.g., the HTTP response), and the remaining content was saved to S3, again using the `WARC-Record-ID` from the WAT file as the key. Theoretically, this process should yield the same number of records as crawl stage; however, five records had corrupted `gzip` entries, yielding 2,127,279 candidate spreadsheets. This stage required about 1,000 normalized instance hours to complete.

3) Filter: The filter stage checks the extracted file and tags those that are actually spreadsheets. Apache Tika's built-in `MimeType` detector was used to return the actual `Content-Type` of the file. If this result was one of the spreadsheet content types, the record was retained. During this stage, we also computed the length (in bytes) of the spreadsheet, identified the most appropriate file extension (e.g., "`.xlsx`"), and generated a SHA-1 digest of the spreadsheet content. At this stage, 719,223 spreadsheets were retained in the pipeline, although many of these may be duplicates. This stage required about 420 normalized instance hours to complete.

4) Plugins: The fourth stage of the pipeline is actually a meta-stage, in which researchers can augment the framework using plugins for their own analysis. For our corpus, we augmented the JSON document with three plugins: `InternetDomain`, which uses the Google guava library to extracts domain-related information from the `WARC-Target-URI`; `Apache POI`, which obtains metrics on the content of the spreadsheets, such as the use of functions; and `LingPipe`, which extracts language-related information from the spreadsheet. These JSON records were all saved to S3 by their `WARC-Record-ID`. For various reasons, not all APIs can analyze all spreadsheets, even when they open in Microsoft Excel. This stage required about 400 normalized instance hours per plugin. Researchers wishing to build on our approach will be able to insert their own plugins at this stage, without having to recompute the first three stages, saving research time and effort. For convenience, we also retroactively ran the `InternetDomain` plugin on the JSON output from the `Match` stage to generate the Web Analysis dataset.

5) Merge: The merge stage simply takes the resulting JSON files from all previous stages and combines them with the original WAT record to facilitate downstream analysis. This stage required about 130 normalized instance hours for each plugin. The output of merge, combined with the spreadsheets from the filter stage, comprise the Binary Analysis dataset.

B. *Local Operations*

We computed a SHA-1 digest of the records from Binary Analysis, from which we performed a local (non-MapReduce), deterministic de-duplication operation. The result of this operation was 249,376 unique spreadsheets. Locally, we also converted all JSON documents to MongoDB format.

IV. Data Schema

The most relevant elements from the Common Crawl WARC record are `WARC-Target-URI`, that is, the URL from which the spreadsheet can be downloaded, and `Container`, which indicates the Common Crawl file and offset used to extract the spreadsheet from the raw crawl data. The `WARC-Date` element may also be of interest, since it contains the time and date of the access. Using the `Content-Disposition` element, one can often extract the original spreadsheet file name.

The Apache Tika JSON element contains four fields, which include the `MIME` type, best-guess file extension, a SHA-1 signature, and the length in bytes of the spreadsheet:

```
{
  "Tika": {
      "Tika-Content-Type":
         "application/vnd.ms-excel",
      "Tika-Extension": ".xls",
      "Digest": "sha1:...",
      "Length": 5123
  }
}
```

The `InternetDomain` element is useful for analysis relating to the origin of a spreadsheet. It uses the `WARC-Target-URI` and extracts the host, the top private domain, and a public suffix[5]:

```
{
  "WARC-Target-URI":
```

[4] https://technet.microsoft.com/en-us/library/ee309278.aspx

[5] https://publicsuffix.org/

```
      "http://www.example.org/results/test.xls",
  "InternetDomainName": {
    "Host": "www.example.org",
    "Top-Private-Domain": "example.org",
    "Public-Suffix": "org"
  }
}
```

Next, we also provide an Alias-i LingPipe element, which extracts the token stream (keywords) from spreadsheets, lowercases these tokens, removes English stop words (such as 'a' or 'the'), and filters out non-words (such as numbers). Again, the representation of this is simple:

```
{
  "LingPipe": {
    "Tokens": [
      "finance",
      "city"
    ]
  }
}
```

Finally, to get a high-level overview of the content of the spreadsheets, we used Apache POI (namespace, POI) to gather spreadsheet metrics. There are over 450 such metrics, which include the number of times a given Excel function (such as SUM or VLOOKUP) is used, the total number of input cells (i.e., cells that are not formulas), the number of numeric input cells, and the most common formula used.

V. TRADE-OFFS

In this section, we articulate the trade-offs of FUSE in the context of other corpora that provide spreadsheets. The EUSES corpus of 4,498 unique spreadsheets, last updated in 2005, is obtained predominately through parsing the top-ranked Google search results for simple keywords, such as "finance" [9]. In contrast, FUSE has no explicit classification for each spreadsheet, though it may be possible to infer a classification using the LingPipe tokens. However, unlike FUSE, EUSES is not reproducible. First, it provides no URL information to obtain the origin for each spreadsheet. Second, the methodology is fundamentally non-deterministic, because Google search results are non-deterministic.

The Enron corpus contains 15,770 spreadsheets extracted from e-mails obtained as legal evidence [10]. Unlike FUSE, Enron is a domain-specific corpus and, consequently, each spreadsheet contains significantly more financial formulas than a general corpus such as ours. In the same vein, FUSE can only offer spreadsheets that are intentionally (or inadvertently) made publicly accessible, and a result, may contain fewer errors than spreadsheets not for public dissemination. On the other hand, FUSE results suggest that formula-heavy accounting spreadsheets are not representative of general spreadsheet users. Finally, the Enron corpus is forever fixed. In contrast, FUSE can accumulate new URLs and spreadsheets as new Common Crawl archives are made available.

Irrespective of other corpora, FUSE has other challenges and limitations. A significant limitation is that Common Crawl restricts its storage of binary files to 1 MB. As a result, large spreadsheets are not available in FUSE. However, if one is willing to give up reproducibility, they may use the 292,043 distinct WARC-Target-URIs from the Web Analysis and download them using a similar technique as WEB [11]. Though FUSE is not as large as WEB (n = 410,554), one advantage is that FUSE contains not only the URL, but also the HTTP response, which includes the crawl access date and Content-Type header.

Yet another limitation is that the methodology for Common Crawl is primarily geared towards text-based HTML pages, not binary files. Consequently, any spreadsheets within Common Crawl are only incidental, and not by design. Finally, our analysis tools do not support very old BIFF5 format spreadsheets.

VI. CONCLUSION

This paper contributes a spreadsheet corpus, FUSE, derived from the Common Crawl. FUSE offers properties not available in existing corpora, including reproducibility and extensibility. Mining software repositories is an inherently cyclic activity: mining data informs insights that require further mining. Our binaries and metadata bootstrap this process, but it is only through custom plugins developed by other researchers that the full potential of FUSE can be realized.

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