Full-Text Indexing for Heritrix

Darshan Karia
San Jose State University

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Full-Text Indexing for Heritrix

A Writing Project Presented to
The Faculty of the Department of Computer Science
San Jose State University
In Partial Fulfillment of the
Requirements for the
Degree Master of Computer Science
By
Darshan Karia
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The Undersigned Writing Project Committee Approves the Writing Project Titled

Full-Text Indexing for Heritrix

By

Darshan Karia

APPROVED FOR THE DEPARTMENT OF COMPUTER SCIENCE

______________________________________________  ____________  
Dr. Chris Pollett, Department of Computer Science  Date

______________________________________________  ____________  
Dr. Mark Stamp, Department of Computer Science  Date

______________________________________________  ____________  
Dr. Jeff Smith, Department of Computer Science  Date
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Abstract

It is useful to create personalized web crawls, and search through them later on to see the archived content and compare it with current content to see the difference and evolution of that portion of web. It is also useful for searching through the portion of web you are interested in an offline mode without need of going online.

To accomplish that, in this project I focus towards indexing of the archive (ARC) files generated by an open source web-crawler named Heritrix. I developed a Java module to perform indexing on these archive files. I used large set of archive files crawled by Heritrix and tested indexing performance of the module. I also benchmarked performance for my indexer and compare these results with various other indexers.

The index alone is not of much use until we can use it to search through archives and get search results. To accomplish that, I developed a JSP module using an interface for reading archive files to provide search results. As a whole, when combined with Heritrix, this project can be used to perform personalized crawls, store archive of the crawl, index the archives, and search through those archives.
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1. Introduction

The Internet Archive [1] project is an open source project intended to store archive crawls of the web. It uses the Heritrix web-crawler [2] to crawl the web and stores web-pages downloaded in archive files. It also tracks the dates when these archives were retrieved from the web and uses that to provide date wise lookup on domains through the “Wayback Machine” [3]. Their mission is to preserve a historical archive of World Wide Web.

This project creates inverted index for archive crawls and facilitates user to search through these archive crawls. It is based on a similar concept established by Wayback Machine, but instead of the domain-based search provided by Wayback Machine, this project provides keywords-based search to a user. A user can perform personalized web crawls limited to domains of interest using Heritrix and store them in compressed archive format. Now a user can use the Indexing Module of this project to index the crawled documents. During indexing, this project calculates a BM25F [4] score for all query words to get more relevant results for user queries while searching. Once indexing is performed and the index is ready, a user can set the Searching Module to point to the newly developed index along with original archive files and search through the crawled documents and to obtain the desired information.
2. Heritrix

In this section, we briefly introduce Heritrix and provide information about where it can be obtained from and how to perform a basic crawl.

Heritrix is an open-source web crawler project used by Internet Archive. It is designed to respect robots.txt exclusion directives and META robots tags. That means, it will not crawl web sites that exclude it using these directives. Heritrix uses an adaptive crawl method to avoid too much traffic on web servers it is crawling.

We now turn to describing how to download and do a basic crawl with Heritrix. Heritrix project is hosted on a sourceforge web-site. It can be downloaded as a binary from the following url:

http://sourceforge.net/projects/archive-crawler/files/

To run Heritrix from the binaries, go to the heritrix-1.14.4/bin directory and type the following command to launch web-interface for heritrix: heritrix --admin=LOGIN:PASSWORD. Here, LOGIN is “admin” and PASSWORD is “letmein”.

If we are running Heritrix from Eclipse as a Java project, we need to set up three parameters in the run configuration before running it. We set the main class of the project to “org.archive.crawler.Heritrix”. We set the program arguments to provide username and password “-a admin:letmein”. We set the VM Arguments “-Dheritrix.development -Xmx512M”.

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After finishing the configurations mentioned above we can launch the Heritrix web based UI. To do this, launch any Web Browser and go to the http://127.0.0.1:8080/ web address to access web based user interface for Heritrix [5].

Before we start crawling the web after our first run on Heritrix, we need to configure a few default settings in the crawl profile. We need to provide values for http-headers like “user-agent” by replacing “PROJECT_URL_HERE” with valid project url and replace “from” with valid e-mail address of the person using the crawler. Also, we need to add new user-agent to “user-agents” under the “robots-honoring-policy” section of the profile. Finally, we need to provide seed sites for the crawl under section “Seeds”.
3. Design and Implementation

We are now ready to describe how we designed each component for Heritrix and what was involved in implementing it. To begin Heritrix generates archive files. We will pass these to our Indexing module to generate an inverted index. This inverted index will later be used by our Searching module to search through the archives. Let’s briefly look at the roles of the Indexing Module and The Searching module:

1) The Indexing Module

It needs to iterate through archive files and construct an inverted index for html files inside the archive. It also needs to calculate BM25F scores for relevance of search results based on query terms.

2) The Searching Module

It provides a Front-end user interface for users to easily search through the index created in first indexing part and get desired results.

Both of above mentioned parts of project are explained in detail in following sections:

3.1 The Indexing Module

The steps to index include but are not limited to iterating through archive files, parsing of html documents, stemming the words, hashing words and docs to create word_id and doc_id, creating a word dictionary, creating a document dictionary, creating the inverted index, and pre-calculating parts of the BM25F score for each word in the word
dictionary. Figure 1 shows the activity diagram for Indexing while Figure 3 shows the same workflow in terms of Java classes and shows the execution flow. Figure 2 represents a class diagram of the Indexing Module. All sub-modules of the indexing module are explained individually through Section 3.1.1 - 3.1.7.

Figure 1: Activity Diagram for Indexing
Figure 2: Class Diagram for Indexing
3.1.1 Iterating through Archive files

The Archive files created by Heritrix are in a GZip compressed format called ARC [6]. We need to read through GZip files to obtain serialized records from the archive file.

Heritrix 1.14.4 has an implementation of org.archive.io.arc.ARCReader class providing us with methods to access records stored in Archive files in random fashion [7]. In order to describe how we iterate through ARC files, it is necessary to describe API of Heritrix [8] a little.

In Heritrix, ARCReaderFactory gives an instance of an ARCReader referring to the provided archive file. One can use its iterator() method to iterate through all records in
the file. Each record is of type org.archive.io.ArchiveRecord. An ArchiveRecord contains header information like the offset of that record in the archive file, and the file type. If the file type is HTML, this module dumps the file into a ByteOutputStream and parses the current record using the parser; otherwise it moves to find next record. It does this for all files within the designated arc directory.

### 3.1.2 Parsing HTML Documents

HTML documents can be parsed in two ways, using DOM Parser or SAX Parser. SAX refers to “Simple API for XML” [9]. In SAX, XML documents are parsed in sequential way and it uses event-based model for parsing. The SAX parser processes XML documents state-dependently. A DOM parser needs to build tree structure in memory based on whole document. A SAX parser is generally more memory efficient compared to DOM parser. A SAX parser, being event-based, only needs to store data related to current event and unclosed tags for reference of close tags. For this project, I have used the SAX Parser implemented in Java [10].

A SAX Parser needs a handler to be defined indicating what to do on certain events like the start of document, the start of element, the end of element, etc. Java has a DefaultHandler class containing all these mentioned methods. I have extended the handler and created my own HTMLHandler class and overridden the methods which I required in order to store the terms in the documents and information about them. The class skeleton looks like the following:
In the preceding figure, the methods are functioning as the names suggest. The explanation of each method is given in Table 1.

Table 1: HTMLHandler Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>startDocument</td>
<td>Called initially when document parsing is started</td>
</tr>
<tr>
<td>startElement</td>
<td>Called each time a start tag is found in document</td>
</tr>
<tr>
<td>characters</td>
<td>Called whenever Character Data is encountered in the document</td>
</tr>
<tr>
<td>endElement</td>
<td>Called each time an end tag is found in document</td>
</tr>
<tr>
<td>endDocument</td>
<td>Called at the end when parser has finished scanning through document</td>
</tr>
</tbody>
</table>

### 3.1.3 Stemmer

Stemming is a process of reducing the derived words to their root forms [11]. E.g. ‘stemmer’, ‘stemmed’, ‘stemming’, ‘stem’, all refers to same root ‘stem’. This helps in consideration of words with same root in search result.
In this project, while parsing html web-pages, stemming is performed on the words before they are passed to a hashing module and stored into the index. For stemming, the open-source Porter Stemmer developed in a language named Snowball was used.

Along with stemming, stop-word removal is also performed before I store the words in the word dictionary. **Stop-words** are the words which have little or no lexical meaning and are used for grammar. A **Posting list** is a mapping from a word to all the documents in which it appears. For more information on these concepts refer to Section 3.1.6.2. A Posting list for stop-words can grow very large based on how common it is in the documents. Very large posting lists can slow down index performance and removing them does not affect search results too much. A stop-word remover will remove all such words to improve indexing performance.

### 3.1.4 Hashing

MD5 hashing is performed on words and document urls to obtain strings of the same length for word_id and doc_id. A class was developed which would perform MD5 hashing based on whether a flag is set or not. If the flag is set, it will perform the hashing of the given string and generate an MD5 hash of that to be used as Id. The first 8 characters from the generated MD5 hash served as an id for the given word or document for its identification. After getting the hashed value of the given string, they are stored in an object of Message class. One object of Message class is used for each document and a list of message objects to process them together after all the HTML documents from current archive file have been parsed.
3.1.5 Word Dictionary

A Word Dictionary uses the word and the first 8 characters of MD5 hashing of the word as described in Section 3.1.4. It consists of a mapping from the word_id to the string word. The word dictionary and inverted index, both are stored using an on-disk Binary Tree data structure implemented in JDBM Project [12]. A Word Dictionary looks like following:

word_id -> Word

3.1.6 Inverted Index

An index refers to a mapping of the document to a set of words appearing in the document. In contrast to that, an inverted index refers to a mapping of the word to set of documents where the word appears. The Inverted Index [13] consists of two basic components, Document Dictionary and Posting List. They are explained in following sections:

3.1.6.1 Document Dictionary

The Document Dictionary contains details for each document in the collection and has a mapping from doc_id to the details of the document. Table 2 below gives the summary of the fields, gives brief information about each of them, and significance of them in this project:

<table>
<thead>
<tr>
<th>Field</th>
<th>Info</th>
<th>Used for</th>
</tr>
</thead>
</table>

Table 2: Document Dictionary Structure
3.1.6.2 Posting List

A Posting List contains information about occurrence of words within collection of documents. It has a mapping from the word to the collection of documents where it appears. This is an important index structure referred to while processing a search query. In addition to a posting list, detailed information about each document appearing in result is retrieved from the Document Dictionary discussed in Section 3.1.6.1. Then for each document corresponding to search term, details are retrieved from Document Dictionary. Details regarding Posting List are explained in Table 3 below:

<table>
<thead>
<tr>
<th>Field</th>
<th>Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>word_id</td>
<td>MD5 hashed word to uniquely identify word</td>
</tr>
</tbody>
</table>
### 3.1.7 BM25F Score

is used to rank plain text documents, while BM25F is used to rank more structured
documents like an XML or an HTML file. The BM25F scoring function gives a
relevance score for a document for the query terms based on the importance of the
element in which the terms appear.

In order to reduce the amount of calculations required to be done in the Searching
Module, the Relevance Scores for the collection of documents based on word-dictionary
is pre-calculated in Indexing Module itself. So, the Searching Module just needs to add
the scores of the document for all query terms and get total BM25F score.

The following sub-sections provide the steps for calculating BM25F scores for a
document based on given query terms:
3.1.7.1 Weight

The weight of the term ‘t’ in the document ‘d’ can be calculated as shown in the following equation:

\[
weight(t, d) = \sum_{c \in d} \frac{occur^{d}_{t,c} \cdot boost_{c}}{(1 - b_{c}) + b_{c} \cdot \frac{l_{c}}{avl_{c}}}
\]

The terms appearing in above equation are explained in Table 4,

Table 4: Explanation for terms in BM25F Weight function

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(occur^{d}_{t,c})</td>
<td>Term frequency of term ‘t’ in document ‘d’ in field ‘c’</td>
</tr>
<tr>
<td>(boost_{c})</td>
<td>Boost factor applied to field ‘c’</td>
</tr>
<tr>
<td>(b_{c})</td>
<td>Constant related to the field length</td>
</tr>
<tr>
<td>(l_{c})</td>
<td>Field length</td>
</tr>
<tr>
<td>(avl_{c})</td>
<td>Average length for the field ‘c’</td>
</tr>
</tbody>
</table>

3.1.7.2 Inverse Document Frequency

Inverse Document Frequency weight of term ‘t’ can be derived using following function:

\[
idf(t) = \log \frac{N - df(t) + 0.5}{df(t) + 0.5}
\]

The terms appearing in above equation are explained in Table 5,
Table 5: Explanation of terms in BM25F idf function

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Number of documents in the collection</td>
</tr>
<tr>
<td>df(t)</td>
<td>Number of documents where term ‘t’ appears (Document Frequency)</td>
</tr>
</tbody>
</table>

3.1.7.3 Final Scoring

Finally, we use the Weight and Inverse Document Frequency calculated for each query term from Section 3.1.7.1 and Section Error! Reference source not found. respectively and use those values in the equation given below to calculate final BM25F score of the document for given query:

$$R(q,d) = \sum_{t \in q} \frac{weight(t,d)}{k_1 + weight(t,d)} \cdot idf(t)$$

The terms appearing in above equation are explained in Table 6,

Table 6: Explanation of terms in BM25F Rank function

<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight(t,d)</td>
<td>Weight of term ‘t’ over all fields for document ‘d’</td>
</tr>
<tr>
<td>$k_1$</td>
<td>Free parameter</td>
</tr>
<tr>
<td>idf(t)</td>
<td>Inverse Document Frequency term ‘t’ over collection of documents</td>
</tr>
</tbody>
</table>
3.1.8 Index Folder Structure

The default directory structure used by the indexing module to organize indexing jobs containing archive files and index files is shown in Figure 5.

![Figure 5: Directory Structure for organizing Indexing Jobs](image)

In Figure 5, the “01”, “02”, “03”, “04”, and “05” directories under “jobs” directory refer to job numbers. The “arcs” directory under each job directory contains the archive files for the particular indexing job. The “index” directory under job directory contains the generated index files for corresponding archive files for the job.
3.2 The Searching Module

An index alone is not useful unless there is a way to use this index for searching through archives for documents. To achieve that, the Searching Module was developed. It is a Java-based Web-application. Along with different modules of Searching Module, it uses some support classes from the indexing module to read index format and archive files. In the Searching Module, there is one search page in which you can enter your query and retrieve results for the same from your archive collection using its index.

The different Use case scenarios for the Searching Module are as shown in Figure 6.

![User Case Diagram for Searching](image)

Figure 6: User Case Diagram for Searching
The Searching Module is divided in mainly three JSP modules:

1. The Query Module

   This module is used for entering search query and displaying results based on that.

2. The LoadCache Module

   This module is used for loading cached version of the document from archive file.

3. The Settings Module

   This module provides various settings related to searching.

All three modules are explained in detail below in Sections 3.2.1 - 3.2.3:

**3.2.1 The Query Module**

This is the main searching module. It consists of index.jsp, IndexReader class, Record class and index itself. Main function of this module is to provide results based on user entered search query.
The workflow of the Query Module is shown in the Figure 7. In the figure, numbers from 1 to 6 represent steps of workflow and they are briefly explained below:

1) The user inputs the query in search box of index.jsp and submits the request.

2) The index.jsp divides the query into list of terms and submits it to IndexReader class.

3) The IndexReader class goes to the currently pointed index and requests for list of documents matching the terms in the query from Posting List. It also retrieves detail for all such document from Document Dictionary.

4) Index provides the requested results back to IndexReader.
5) The IndexReader class builds the list of Record objects by using the details obtained from index and combining BM25F scores for each document where search query term appears. At the end, it sorts the List of Record objects in descending order of BM25F score. This List of Record objects is sent to index.jsp file for user to see.

Here, every Record object contains important information for search result like Title, the link to the original document, the information needed to load cached version of document and snippet of the document content when available.

6) The index.jsp file displays the formatted result for the user query on the page. Sample of search results for query “google” showing records can be seen in Figure 8.
3.2.2 The Load Cache Module

This module takes request from the Query Module to retrieve the archived version of document based on file name of the archive file containing the document and offset for that result within that archive file. It shows the html document on screen to user. It might lack certain pictures or formatting of the document if the original pictures and cascaded styles sheets linked to the document are no longer available.

Workflow of the Load Cache Module is shown in Figure 9 and it is explained below according to the numbers given in the figure.
1) User selects the document to load from archive by using “load from cache” link for corresponding document.

2) The required details to locate and load the selected document from the archive file are passed as parameters to loadCache.jsp. These details include name of the archive file where it is stored and offset to the record containing document.

3) loadCache.jsp locates the archive file based on the information provided and location of all archive files related to the index provided by config.properties file. Using ARCReader class, loadCache.jsp requests index for the document at in provided archive file, at given offset.

4) Archive file returns the record containing the requested document to loadCache.jsp

5) loadCache.jsp reads that record and returns it to the user.
3.2.3 The Settings Module

This module allows the user to change various parameters related to the index and archive files. The Query Module and the Load Cache Module refers to the settings saved through this module. This module consists of the settings.jsp and the config.properties file.

In the settings.jsp, the user is provided an option to retrieve or change settings related to indexing and archive files.
Figure 10: Settings Module

Figure 10 shows how the settings on web-page look like. Those settings are explained in Table 7 with their default value. These settings will determine behavior of entire web-application.

Table 7: Settings of MySearcher

<table>
<thead>
<tr>
<th>Setting</th>
<th>Option</th>
<th>Default Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>jobs_path</td>
<td>Path to jobs folder where archive jobs are stored</td>
<td>Jobs/</td>
</tr>
<tr>
<td>job_id</td>
<td>The job id in the jobs_path to refer</td>
<td>01/</td>
</tr>
<tr>
<td>arcs_dir</td>
<td>Path to directory containing archive files relative to jobs_path.</td>
<td>Arcs/</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>index_dir</td>
<td>Path to directory containing the index file relative to jobs_path</td>
<td>Index/</td>
</tr>
<tr>
<td>index_name</td>
<td>Name of the index file</td>
<td>MyIndex</td>
</tr>
<tr>
<td>debug_flag</td>
<td>Prints debugging information on console</td>
<td>false</td>
</tr>
</tbody>
</table>

Figure 11 shows the workflow of how Settings Module saves configuration file. The steps from the figure are explained below based on the numbers assigned:

1) User opens the settings.jsp file. The settings.jsp file retrieves the key-value pairs from configuration file as label-input pairs on generated html page.

2) The settings.jsp updates the values in the configuration file upon user request by clicking the save button.

3) Updated values are reloaded on the settings.jsp page.

4) A JavaScript function redirects user to index.jsp in 3 seconds after update is performed. This time period gives user chance to see the changes.

5) index.jsp is displayed to the user for him to start searching based on the newly updated configuration.
Figure 11: Settings Module Working Diagram (Save file)
4. Testing and Results

4.1 Results for Indexing Test

I tested my Indexing performance by indexing 38 archive files of size 3.49GB. These archive files were retrieved from a Heritrix crawl ran on April 11, 2011 on sjsu.edu domain. Below is part of the result also demonstrating profiling of the indexer:

Path: jobs/03/arcs/

Following files are found:

*IAH-20110411213501-00000-130.65.104.126-8080.arc.gz
Phase - I of iterating arc files and parsing html docs started... 0 Seconds
Phase - I of iterating arc files and parsing html docs finished... 15 Seconds and 15 Seconds from start to end
Phase - II of processing messages and creating index started...15 Seconds so far
Phase - II of processing messages and creating index finished...7 Seconds and 22 Seconds from start to end

*IAH-20110411213510-00001-130.65.104.126-8080.arc.gz
Phase - I of iterating arc files and parsing html docs started... 24 Seconds
Phase - I of iterating arc files and parsing html docs finished... 19 Seconds and 44 Seconds from start to end
Phase - II of processing messages and creating index started...44 Seconds so far
Phase - II of processing messages and creating index finished...31 Seconds and 75 Seconds from start to end

*IAH-20110411221922-00037-130.65.104.126-8080.arc.gz
Phase - I of iterating arc files and parsing html docs started... 12912 Seconds
Phase - I of iterating arc files and parsing html docs finished... 0 Seconds and 12912 Seconds from start to end
Phase - II of processing messages and creating index started...12912 Seconds so far 
Phase - II of processing messages and creating index finished...533 Seconds and 
13446 Seconds from start to end

Phase - III of pre-calculating BM25F score started...13446 Seconds so far... 
Current Working Directory: C:\Users\Darshan\workspace\MyIndexer 
invertedIndexTree exists and has 56900 members 
docDictionaryTree already exists and has 22479 members 
miscTree already exists and has 5 members 
Phase - III of pre-calculating BM25F score finished...243 Seconds for this phase 
and 13887 Seconds from start to end 
24109 html files processed...

As you can see above, it took around 13887 seconds to create index for 38 archive files of 
total size 3.49GB. It retrieved 24109 html documents out of those archive files and 
created index based on them. Size of created index is roughly ~700MB.

4.2 Results for Searching Test

To test the performance of the Searching Module, I used the index created for the test 
performed in Section 4.1. It has approximately 25,000 documents indexed on sjsu.edu 
domain from April 11, 2011. The original archive size is approximately 3.50GB. I used 
The Settings Module of The Searching Module to use this desired index and set of 
archives for The Query Module.
Figure 12: Search Results Test

**Speed Test**

Now, as shown in Figure 12 performing search for “computer Science” query in the Query Module, it retrieves 1626 results for the query “computer science” in 0.312 seconds.

Table 8 represents more search results benchmarking obtained using the same methodology explained above. This test helps to get an idea of average performance of Searching Module for various queries.

<table>
<thead>
<tr>
<th>Query</th>
<th>No. of Results</th>
<th>Time Taken</th>
</tr>
</thead>
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<td>Department of Computer Science San Jose State University</td>
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</table>

Table 8: Speed Test Results
Figure 13: Graph for Time Taken for Query

Figure 13 represents the Query vs. Time Taken graph. Figure 14 represents the Query vs. No. of Results graph. Both of these graphs use data from Table 8.

As we can see in Figure 13, the time taken to retrieve the result generally increases as we introduce more terms in the search query. If we combine this finding with results shown
in Figure 14, we can derive that Time taken to retrieve result increases as we introduce more terms in search query or if there are more results to process and sort.

**Figure 14: Graph of No. of Results for Different Queries**
5. Technical Difficulties & Limitation

“In a day when you don’t come across any problems — you can be sure that you are traveling in the wrong path.” – Swami Vivekananda [15]

As the quote suggests, one cannot finish a task without facing any challenges or difficulties. This project was no exception. Some of them are predicted during research work, while others are only to be seen during implementation.

This section contains one such Technical Difficulty and its workaround:

5.1 **GZIPInputStream bug**

This project processes GZIP files for processing of Archive Records. GZIP file format [16] specifies that single GZIP file can accommodate multiple members provided each members have their own headers specified.

Java’s implementation of GZIPOutputStream allows producing such files, while GZIPInputStream fails to read more than one members from the GZIP file. There is a known bug for this reported to developers of JDK [17]. They tried to fix this in JDK 1.6.0_23 (update 23), but that still has bug in its implementation and old work around by Heritrix Developers to original bug no longer works due to the code change within the method for reading stream through GZIP file.

In order to use ARCREader class provided by Heritrix 1.14.4 for archive reading, the version of Java Runtime Environment has to be 1.6.0_22 or below.
6. Conclusion

Full-text indexing for Heritrix, in combination with Heritrix, provides everything one may need to create searchable archives. To make the archives generated by Heritrix searchable, this project adds the Indexing Module to generate inverted index for the archive files and the Searching Module to provide a web-based search interface facilitating users to perform search through these archives.

Heritrix crawls the web and stores documents in archive file. Our Indexing Module of this project uses these archive files to create Inverted Index for them. The Searching Module provides the web interface for users to search through the archived documents using the inverted index along with archive files. The returned results have links to view archived versions of documents as well as current versions of the documents if they are currently available on web.

This project serves three purposes:

1) It provides keyword based searching compared to Internet Archive project, which provides only domain based searching.

2) It can be used for archiving different versions of the web referring to different times and see the evolution of the web by pointing the search engine to different indexes and comparing the cached documents.
3) It can be used for archiving of important documents in case either they are no longer available online due to certain reason or you do not have internet connection and want to search through those documents.
8. References


