Project: Search Engine

Group: ip18groupR

IT UNIVERSITY OF COPENHAGEN

Group name: Busca.*
Introductory Programming
Master of Science in Software Development
IT University of Copenhagen
December 14, 2018

Contents

0.1 Introduction

The goal of this project is to develop search engine as part of the Introductory Programming course at the IT University of Copenhagen. Sections 2- 4 are reporting the solutions on the mandatory tasks posted in the project description, namely Faster Queries using an Inverted Index, Refined Queries and Ranking Algorithms. Each of the mandatory tasks contain description of the

- Taks, which is introduction of the task that have to be solved in the given section;
- Basic Approach, which describes the solution;
- Technical description, explaining the software architecture used in the solution;
- Testing considerations, considering the corresctness of the solution;
- Benchmark/ Reflection, includes benchmarking results or other conclusions based on the observations or theoretical considerations;

Besides the mandatory tasks, the challenge of the implementating OkapiBM25 algorithm for the task Ranking Algorithms have been solved as well. Some extensions also have been implemented, namely:

- Changes to the client GUI
- Implementation of the WebCrawler

0.2 GitHub

0.3 Project Delivery

The project documentation have been submitted via learnit.dk and the source code that accompanties this report as a singel zip dile called ip18groupR.zip has been handed alongside with this report. The code is also available on ITU's GitHub: https://github.itu.dk/wilr/ip18groupR
To start the program one should:

1. Download the zip file;
2. Select directory for saving the file;
3. Open the Command Promt;
4. Find the directory, where programm files have been saved;
5. Build the Gradlew by calling *./gradlew* for Linux users (L) or *gradlew* for Mac and Windows users;
6. To start the server as a Spring boot application use the command *gradlew runWeb*;
7. After the server is started, open a browser and type in *http://localhost:8080/*;
8. Start searching by typing in search queries in the search textbox shown on the HTML page and press Enter on the keyboard or *Busca* button;
9. To have an overlook on other tasks performed by gradlew, call *gradlew tasks*;

How to change the index file:

- Easiest way to change the index file is to open the *configuration.properties* file and change the database property to a different file;
- Other way to change the index file is to give the file path as arguments *(args w/ –args)* when calling the gradle task *runWeb*

How to start the extension WebCrawler one should:

- Call the gradlew task by writing the command *gradlew startWebCrawler*;
- Every time the WebCrawler have visited a web page it will append it to the *real_data_file.txt in the data*;
- One has to make sure there are no previous WebCrawler running into the background, as it will continue to add results to the *real_data_file.txt in the data*;
- In order to search throught the WebCralwer results, the *real_data_file.txt in the data* have to be used as index file for the search engine;
- In order to search throught the historical WebCralwer results where data set have been build for under six hours, the *real_data_file_20181213.txt in the data* have to be used as index file for the search engine;

0.4 Statement of Contribution

All authors contributed equally to all parts of the mandatory tasks. Ashley Rose Parsons-Trew took up the challange of implementing OkapiBM25 algorithm for the task Ranking Algorithms, Hugo Brito made the graphic design and the client GUI extension, Ieva worked with the WebCrawler extension and Jonas Hartmann Andersen enabled the team to successfully work whith this GitHub.

Chapter 1

FileHelper

1.1 Task

This chapter is comprised of the changes and improvements done on the `FileHelper` class, which can be found in the folder src/main/java/searchengine. The intended functionality of such class is to parse a file containing data about websites, returning its result as a `List<Website>` to be used later on for by other parts of the program.

1.2 Basic Description

The `parseFile` method is designed to take in parse a file and extract all the websites that are contained in the file. It features the following:

- `@param filename` — The filename of the file that we want to load. It needs to include the directory path as well.
- `@return` — The list of websites that contains all the websites that have both titles and words that were found in the file.

Each file lists a number of websites including their URL, their title, and the words that appear on a website. Moreover, it should only take in consideration data on websites that fulfilled the following format:

```
*PAGE:http://www.websiteURL.com/
Website's title
word 1
word 2
...
word n
```

This meant that, for a website to be passed on to the index, it must have a title, an URL, and the amount of words has to be more than zero.

1.3 Technical Description

As part of the set up of this task, the `FileHelper` class — specifically the `parseFile(String filename)` method — was updated such that from the database file, only websites that have a url, title, and at least one word of webpage content are read-in and stored in the server.
This was accomplished by an `if` statement to check the assignments of the URL and title fields prior to adding a `new Website` object to the `ArrayList<Website>`. However, the major of the changes made to this method were to how the method recognised the content of each line scanned in in order to know how to treat it. Previously, this was accomplished by making use of the knowledge of the very specific file format, `String` methods, and `boolean` field variables. This was all replaced by two regular expressions:

```
Pattern website = Pattern.compile("(https?:\\/\\/[A-Za-z0-9.\\/_]+)");
Pattern webTitle = Pattern.compile("[A-Z][a-z]+[A-Za-z0-9\\s]+?");
```

This was followed by methods of the `Matcher` class.
Even though it does not look to be that big of a change, doing so means that the two field variables are no longer needed. It also enforces correctness when parsing a file that might not be in the intended format.

1.4 Testing

White-box tests were developed around the branching statements in the updated method, taking into account positive and negative testing. From these, a coverage table was produced (please refer to Appendix A.1) and the expectancy table (Appendix A.2) followed. Please note that while `try` and `catch` cases were considered the `catch` call was disregarded as the `exception` was already being handled.
The data set data/test-file1.txt is an empty file, and the rest contained the data shown in A.3. This process using the Coverage and Expectancy tables shown in Appendix A is an example of how we construct our tests. JUnit tests were then produced from table A.2, as found in `FileHelperTest.java`.
Correctness was verified along two axes:

- the size of the `List<Website>` returned,
- the specific contents of the `List`.

As you can see from the Actual Output column of A.2, the updated code failed test B3, highlighting a weakness in the code, and subsequently had to be debugged. Including another `if` statement after the `while` loop resolved the issue, and following that all tests were passed.
Lastly, a test to check if the websites contained in the `Index` were the same as the websites read by the `FileHelper` class was written and performed. This was performed on the tiny, small and medium files and was meant to see whether the behaviour of the `index` would stay the same when the database size changed.

Chapter 2

Faster Queries using an Inverted Index

2.1 Task

When using a search engine, the most important aspect is to be able to perform a search and get the results almost instantaneously. One way of doing this is by using an `InvertedIndex`, which sorts the websites according to the words contained in each website. Hence when searching for a specific term, instead of going over every word contained in every website, it will retrieve websites mapped to the search term. While building the `InvertedIndex` can be system heavy, it is a one time operation that will allow the search engine to answer queries significantly faster.

2.2 Basic Approach

All the files regarding the classes mentioned on this chapter can be found on the folder src/main/java/searchengine.
The `Index` was generalised into an interface to make it easy to test the different

indices and switch between them. The following methods define the aforementioned `Index` interface:

- `build` — Processes a list of websites into the data structure.
- `lookup` — Given a query `String`, returns a list of all websites that contain the query.
- `provideIndex` — Provides all websites in a given `Index` as a collection.

The inverted indices were then implemented using inheritance, since both the `InvertedIndexHashMap` and `InvertedIndexTreeMap` can be given exactly the same methods, the only difference being their individual data structure.

2.3 Technical Description

As previously stated, a generalised `Index` interface was created. Each of the classes below implements this interface, visualised in 2.1.

2.3.1 `SimpleIndex`

The provided default way of indexing data was called `SimpleIndex`. The `build` method simply takes a list of websites and stores it in its `field`, while the `lookup` method is implemented looping through every word of every website, storing the matching websites on an `ArrayList<Website>`.

2.3.2 `InvertedIndex`

The second (and improved) approach to index the data was to use an `InvertedIndex`. As the name implies, here the relationship between a website and its words is inverted, meaning that each word knows to which websites it belongs. In Java terms, `Maps` are used where every word is a `Key` with an associated `Value`, which consists of an `ArrayList<Website>`.
This class implements methods of the `Index` interface, buts ince it did not make sense to create instances of of it, it was made `abstract`.

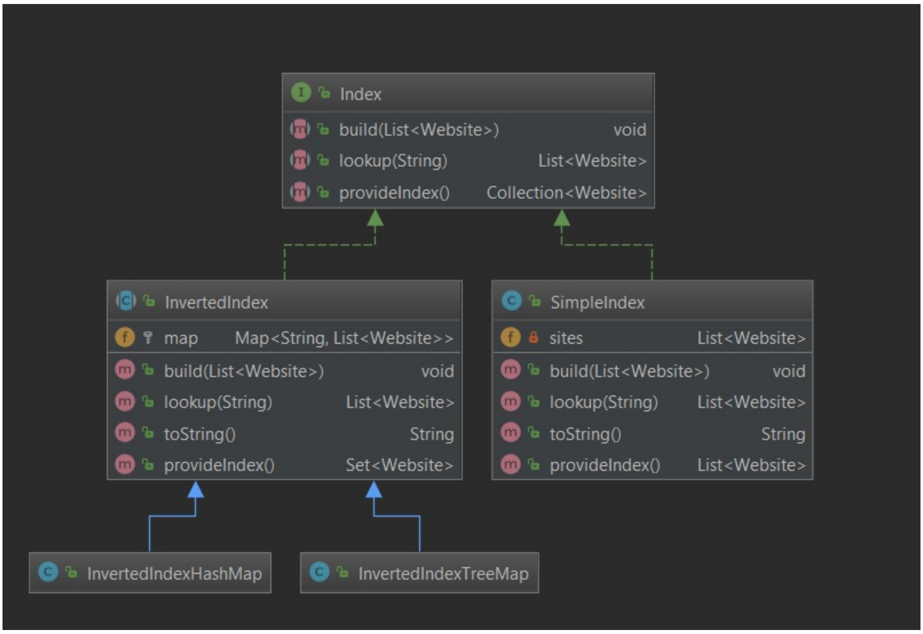


Figure 2.1: UML Diagram for the Software Architecture of Index data structures.

2.3.2.1 `InvertedIndexTreeMap`

This class `extends InvertedIndex`.
The `TreeMap` sorts its keys either by the natural order or by a `Comparator`. It provides guaranteed *log(n)* time performance for the operations **containsKey**, **get**, **put**, **remove**. Oracle (2018b) `TreeMap` uses only the amount of memory needed to hold its items, therefore this solution is suited when it is not known how many items have to be sorted in memory and there are memory limitations. Solution is also suited when the order in which items have been stored is important and the `O(log n)` search time is acceptable.Baeldung (2018)

2.3.2.2 `InvertedIndexHashMap`

This class `extends InvertedIndex`.
The underlying data structure of the `HashMap` is a hash table based implementation. This implementation provides *constant-time* performance for the basic operations such as **get** and **put**. Oracle (2018a) However this is true under

assumption that there are not too many collisions. This is because this `Map` implementation acts as a basket hash table and when buckets get too large, they get transformed into tree nodes, similar to those of `TreeMap`. Baeldung (2018)

2.4 Benchmarking

In order to choose one of the implementations for the search engine, the benchmark test was performed to gain empirical data of the performance of each of the implementations. For the benchmark test, JMH (a Java harness for building, running, and analysing nano/micro/milli/macro benchmarks) was used. (OpenJDK, 2018) The benchmark test was carried out using 20 words (random nouns, verbs, adjectives and conjunctions), which were looked-up using the three different `Index` implementations and in three different size databases: `enwiki-tiny`, `enwiki-small`, `enwiki-medium`. JMH then provides information about an average Score, measured in nanoseconds per operation, the results of which can be found in table 2.1.
During the benchmark it was assured that the test environment is as similar as possible among the different trials, meaning that all tests were performed on the same machine and no other applications running on the background.

Table 2.1: Benchmark Scores. Each score is an average in ns/op

Data set	Simple Index	Inverted Index	
		HashMap	TreeMap
enwiki-tiny	18 944,884	1 052,067	1 591,311
enwiki-small	8 819 338,592	1 883,776	3 622,582
enwiki-medium	233 498 546,571	27 451,020	30 176,993

The benchmark results shows that the `SimpleIndex` is significantly slower than both of the `InvertedIndex` implementations: 233 498 546,571 ns/op versus 27 451,020 ns/op for the `InvertedIndexHashMap` and 30 176,993 ns/op for the `InvertedIndexTreeMap` using the `enwiki-medium` dataset. In order to describe the results, let the number of websites be m and words be n. The difference in performance can be explained as follows:

- When the `SimpleIndex` is looking up the search word, it looks through all the websites, which takes $O(m)$ time; and for each website it looks through all the words which takes $O(n)$ time. Therefore total search time is $O(m \cdot n)$.
- The two other methods provide faster performance time:

- `InvertedIndexTreeMap` provides a *guaranteed* performance of *O(log(n))*.
- `InvertedIndexHashMap` provides best-case performance of constant time *O(1)* and the worst-case performance of *O(log(n))* time (since Java 8). Worst-case performance occurs when the hash function is not implemented correctly and values are distributed poorly in buckets, leading to high hash collision.

There are several considerations when choosing the implementation for storing the data for the Search Engine:

- `HashMap` seems to be better fit than a `TreeMap` for our search engine implementation, because in this case the order of data is not important whereas the performance looking up the websites corresponding the search word is.
- The `HashMap` can be expected to perform in constant time which is better than `TreeMap`'s *log(n)* time, and only in the `HashMap`'s worst-case performance is it *log(n)* time.
- `HashMap` performed the best on all of the given data sets in benchmark test, and for this reason we decided to use it.

2.5 Testing Considerations

After the above changes were implemented, development tests were written in order to determine the viability of the code and whether the changes satisfied the requirements of the task. To that end, JUnit tests were devised for each class that was updated. Positive testing was done, specifically around the limits of valid inputs.
The correctness of the `build` and `lookUp` methods were verified using unit tests, which can be found in the `IndexTest` file.
When setting up the test, a small `List<Website>` was created which made it easier to predict the expected results of the methods. Each test checks all of the indices using the white-box coverage considerations. The `SimpleIndex` were more used as a reference to the others, and the tests as it should be able to pass all test, due its simple nature.
The `build` method was verified by creating a `String` of what was expected the index should contain and then calling the `toString` on the index.
The `lookUp` method was tested by providing it with words and then checking the size of the list returned against the expected size of that list.

Chapter 3

Refined Queries

3.1 Task

This task enables complex query handling. This is a basic feature that is expected from a search engine: to be able to understand queries that consist of more than just one word (intersected search: all words m). Additionally, the task required the search engine to be able to handle aggregated results from different (possibly) multi-word queries when the 'OR' keyword is present (unioned search).

3.2 Basic Approach

All the logic necessary to handle the queries was implemented in the class `QueryHandler`. When considering what needs to be accomplished as well as what the user can input in the search field, the present task is accomplished by following these steps:

1. Sanitise the query: this comprises of checking if the query is meaningful and fulfils basic criteria in morphological terms, and to enforce it in the

cases it does not.

2. Separate the query into sub-queries whenever the 'OR' keyword is present.

3. For each of the sub-queries, find websites that contain all the words in that sub-query.

4. Aggregate all the results of the multiple sub-queries on a list.

In order to achieve encapsulation and responsibility-driven design, the following methods were implemented in the above-mentioned class:

- `getMatchingWebsites`: Core method of the class. It is responsible for:
  - Receiving the input and passing it to the `cleanQuery` helper method.
  - Receiving the return `List<String>` from the `cleanQuery` method and passing it, element by element, as a parameter to the `intersectedSearch` method.
  - Receiving every result of the `intersectedSearch` method and store it, so that when every element of the list is processed, it returns the matching websites.
- `cleanQuery`: Auxiliary private method to make sure that the input is free from unaccounted or irrelevant input.
- `intersectedSearch`: Auxiliary private method that returns websites that match simultaneously all the words in the input `String` parameter.

3.3 Technical description

3.3.1 Field

The `QueryHandler` class takes an `Index` object and a `Score` object as the initialising parameters and assigns them to private fields. The `Index` can be any of the indices described in the previous chapter as all extend the same `Interface`. The same can be said for the `Score` interface, and the details of this can be found in the next chapter.

3.3.2 `getMatchingWebsites` core method

As soon as this class is instantiated, its intended use expects the `getMatchingWebsites` method to be called. This method takes in a `String` as parameter, which consists of the search terms and returns a `List<Website>`, which consists of the matching results. As the description in the Basic Approach states, this method uses two auxiliary methods to process the data as necessary. The first data processing happens when the parameter is passed to `cleanQuery` method, which then returns a list of Strings that can be used to proceed with the search.

3.3.3 `cleanQuery` auxiliary method

This method enforces consistency in the input to be later on used to search for results. The first steps of the process consist of:

- Replacing all the punctuation characters by spaces
- Replacing every one or more space characters by a single space character

The above mentioned steps are achieved by making use of the `String` method `replaceAll`.

```
private List<String> cleanQuery (String input){
    input = input.replaceAll("\\p{Punct}", " ").replaceAll("\\s+",
        " ");
```

After this, the 'OR' keyword is used as criteria for splitting the input `String` using the `split` method, which is then used to create a `List<String> searches`. The idea is that every element of the list will consist of an intersected search, and the search results of each element will then be aggregated to achieve the final result. The `split` method gives `String []` as a result, but is then parsed as an `ArrayList<String>` as this is more maleable, and through the `java.util` methods allows for the consistency in the `List<String> searches` to be enforced (such as trimming all the searches in case they start or end with empty spaces, deleting all empty entries in the `List<String>`, and making everything lower case due to the way the website content is stored in the index). This was elegantly achieved by using lambdas.

```
searches.replaceAll(String::trim);

searches.removeAll(Arrays.asList(""));

searches.replaceAll(String::toLowerCase);
```

3.3.4 Intermediate steps in the getMatchingWebsites method

The refined search query, now stored in a List<String>, is iterated through and each element passed as a parameter to the auxiliary method intersectedSearch, the results of which are stored in a Set<Website> results. The root of the reason for the choice of such data structure is the fact that it does not allow duplicates (as opposed to a List, which expedites the process. Since we intend to iterate through a set of data, it seemed appropriate to implement a for loop.

3.3.5 intersectedSearch auxiliary method

Given a certain String parameter, this auxiliary private method returns a Set<Website> where each Website matches simultaneously all the words in such parameter. The idea is that:

- The String parameter is split by space characters using the split method.
- The resulting String[] is converted to an ArrayList<String>.
- The lookup method, using field Index idx, is called on the first element in the ArrayList<String>.
- The result of this is stored in a HashSet<Website>.

Should there be more than one String in the ArrayList<String> i.e. more than one word in the parameter String to intersect the first set of results with, these results will be used to compare with the results of the remaining String in the ArrayList<String>. In order to accomplish such task, the results of every other given word were successively compared with the results from the first element of the list. The refining criteria was to keep only the websites that were present on both lists. To this end, the Set method retainAll was utilised.

3.3.6 Final steps in the `getMatchingWebsites` method

All the results from each of the different intersected searches performed by the `getMatchingWebsites` method are added to a `HashSet<Website>` (again, to avoid any duplication of websites), which is then passed to the `rankWebsites` method and returned as a `List<Website>`. The details of the `rankWebsites` method will be discussed in more depth in the next chapter.

3.4 Testing considerations

Upon testing for correctness, we split the test cases in two main groups: one that tests basic functionality using valid data (positive testing), and a second one that tests functionality with bad user behaviour (negative testing). To determine the expected results from the tests we copied each website from enwiki-tiny.txt into a separate regex101.com and used the following regex to help determine whether the words were on the website:
Regex = $(?:|$
$W)word(?:|$
W)
Where word is the given word wanted to find in the website.

- Testing for the basic functionality:
  - One word
  - One or more words separated by spaces;
  - Two words with the "`OR`" keyword in between;
  - Groups of words separated by the "`OR`" and by spaces;
- Testing for bad user behaviour, where the query:
  - Is empty;
  - Starts with white space followed by the "`OR`" keyword;
  - Repeats the words separated by the "`OR`" keyword;
  - Consists of solely the "`OR`" keyword;
  - Starts with the "`OR`" keyword followed groups of words separated by spaces;
  - Starts with white space followed by the "`OR`" keyword followed groups of words separated by the "`OR`" and by spaces and ends with "`OR`" ;

- Consists of only white space;
- Starts with punctuation and white space and is followed by a group of words separated by spaces;
- Consists of several `"OR"` keywords separated by spaces, followed by a group of words separated by spaces and ends with several `"OR"` keywords separated by spaces;
- Consists of several words separated by the `"OR"` keyword where there is more that one `"OR"` occurrence between words;
- Contains only upper case characters;
- Contains no spaces but a word surrounded by several `"OR"` keywords;
- Contains an upper case word next to an `"OR"` keyword with no spaces in between, followed by another `"OR"` keyword and a word.
- Lastly, we considered the worst case scenario where a query contained many of the above-mentioned cases and also for when there was punctuation between words.

3.5 Reflection

This task set out to enable the `QueryHandler` class to handle more complex queries (i.e. multi-word queries referred to as intersected queries, and queries making use of the `"OR"` keyword which are referred to as unioned searches). Due to the fact that this update involved merging the results of individual searches on single words to return an amalgamated `List<Website>`, `Set` was used liberally to avoid duplication of `Website` results. Regular expressions were used to parse the search query quickly in the `cleanQuery` method, and the `String []` were converted to `ArrayList<String>` for flexibility as `ArrayList` offers methods that were integral in sanitising the original search query.

Chapter 4

Ranking Algorithms

4.1 Task

Typically, results returned from search engines are ranked so the more relevant search results first are featured on the top of the list. The general idea behind this is that, for a given website, a score is calculated for each word to indicate the importance of that word on such website.
As a query might consist of a union of a certain number of intersected searches, the score is calculated as follows:

- Intersected Search: the score is a summation of the scores for each individual word in the search;
- Union Search: the score is taken as the maximum of the score for each part of the union search.

This score should then be used to order the results of a given query.

4.2 Basic Approach

For this task, the following ranking algorithms were introduced:

- Term Frequency (TF)
- Term Frequency — Inverse Document Frequency (TFIDF)
- Okapi BM25 (which is discussed in detail on the Extensions section of this paper)

Please note that these consist of different implementations of the same aforementioned general idea: assigning a score to a website based on some metric of relevance.
Research was conducted into the implementations of each of the ranking algorithms.

4.2.1 Term Frequency

The TF is simply this: given a word and a document (which in this case, is a webpage), how many times does a word appear on that document? (Luhn, 1957)
Even though there are various implementations on this basic formula, the TF formula settled on in the end was:
Let

- TF be the term frequency
- f be number of occurrences of a given word on the website
- w be the total number of words on that website

We have:

$$TF = \frac{f}{w} \tag{4.1}$$

Such formula enabled us to add a layer of normalisation on the score, as a word occurring 10 times on a 50-word-long website has a different significance to a word appearing 10 times on a 500-word-long website.

4.2.2 Term Frequency — Inverse Document Frequency

Before the $TFIDF$ algorithm can be discussed, the idea behind "Inverse Document Frequency" must be explained.
The idea behind the inverse document frequency is that, while the number of times a word appears on a webpage is a good indication of how important that word is to that webpage, there are many common words such as "the", "and", "this", etc., that will inevitably appear multiple times on a website and will therefore skew the score of any kind of score based on term frequency (Jones, 1972). The inverse document frequency formula is designed to take this into account and is calculated as follows:
Let

- IDF be the inverse document frequency
- s be number of websites in the search engine index
- sw number of websites containing the word

We have:

$$IDF = log_2\left(\frac{s}{sw}\right) \tag{4.2}$$

Taking the log of this ratio means that, the more times a word appears on a website in the database, the closer the IDF gets to 0, and a word that appears on every website in the database is awarded an IDF value of 0.
In other words, common words that are likely to appear on multiple (if not all) websites will have no impact on the ranking score. With that in mind, the meaning behind the $TFIDF$ ranking algorithm becomes clear. By (4.1) and (4.2), the $TFIDF$ score is calculated as follows:

$$TFIDF = TF \times IDF$$

The TF score judges the relevance of the word to the website, and the IDF is a weighting to adjust for common words. Very common words are awarded a $TFIDF$ score of 0 (or close to 0) and therefore give no impact in intersected searches.
It was also decided that the various implementations of `Score` classes created would be solely responsible for the calculations.

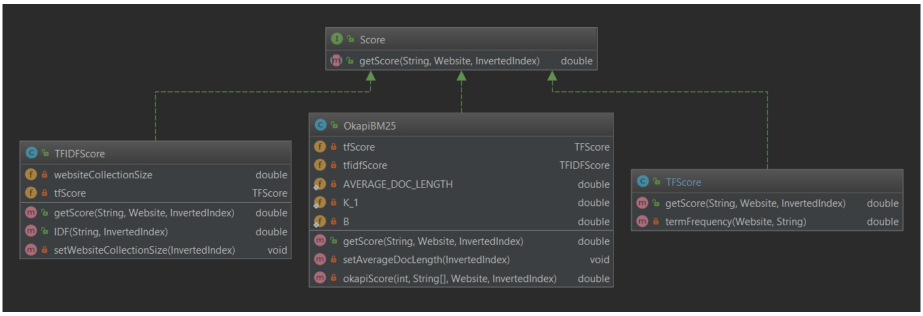


Figure 4.1: UML Diagram for the Software Architecture of Score data structures.

4.3 Technical Description

As per the task description, a generalised `Score` interface was created with only one method — `getScore` — which performs the score calculation for the given word with the given website, taking the following parameters:

- `@param word`: a word from the search query
- `@param site`: the website being scored against the search string
- `@param index`: the index of websites

Each of the below classes implement this interface. In addition to this, the `rankWebsites` method was added to the `QueryHandler`. That essentially takes one of the given ranking algorithms and scores the websites relevant to the query and then order them from highest to lowest. This method will also be used by the OkapiBM25 algorithm.

4.3.1 `TFScore` class

The `TFScore` class was the simplest of the three classes to implement, as shown in Figure 4.1. Due to the changes made to the `FileHelper` class — namely, that no website that lacks a title or words can be created — it's not possible for there to be a divide by zero error, so no steps were made in this method to account for it.

4.3.2 `TFIDFScore` class

As the $TFIDF$ makes use of the TF calculation, the `TFIDFScore` class was given a field of type `TFScore` with which to call methods on as needed, rather than creating a new object each time it was required. Helper methods were added to deal with the different aspects of the calculation, i.e. the IDF and the number of websites in the search engine index. Also, in order to enable any `Index` to work with this implementation, a helper method was added there — `provideIndex` — which returns a `Collection<Website>`, much needed to compute this. The number of websites was built from the `Index Map<String, Website>`. Such implementation makes use of the fact that a `HashSet` allows no duplicates in order to calculate the number of distinct websites in the `Index`.
Again, the `getScore` method only handles the multiplication.

4.4 Testing considerations

The mathematical correctness of the score calculations were verified using unit tests, which can be found in the ScoreTest.java file.
The positive testing approach was applied in this context. The set up comprised of building a small number of websites, which allowed for the score values of various words on various websites to be calculated manually and compared to the results of the `getScore` method.
Each test covered one class, and the individual tests were determined using the standard white-box coverage considerations. For the tests on the `TFIDFScore` class, a comparison was also included to confirm that a word occurring once on more than one site will have a lower score than a word occurring once on just one site.
The application of the algorithms were tested in the RankScoreTest.java file. White-box and positive testing were used in these tests. The test checked whether ranking algorithm TF and $TFIDF$ would rank the websites correctly. The two ranking algorithms were testing websites which were set up specifically for the tests to allow easier prediction of how the ranking should be. Two websites in the `setUp` was made to create noise, to see how the algorithms would react to them.

4.5 Reflection

After implementing the two different ranking algorithms and testing their implication it was possible to compare the different results they provided. While the TF algorithm sums together the term frequency of each word in the search query, the $TFIDF$ algorithm also considers the relative frequency of each of the words in the search query appearing across the collection of websites on which the search is performed. This means that if the search query would consist of, e.g. "Queen of Denmark", the $TFIDF$ ranking algorithm would provide more relevant results than the TF algorithm, because one could assume that the word "of" would appear significantly more often across different websites, than words "Queen" or "Denmark". Therefore, while the unit tests were used to verify the mathmatical correctness of the algorithms, the test in `RankScoreTest` was also set to demonstrate the potential relationship between the search query and the background of the rest of the websites in an abstract and simplified manner.
Based on the theoretical assumptions on the relevance of the two algorithms when applied to querying, and their behaviour in the `RankScoreTest`, it can be concluded that the $TFIDF$ is the most relevant to as it provides a more appropriate result to the user's search query.

Chapter 5

Extensions

5.1 Okapi BM25

5.1.1 Basic Approach

The Okapi BM25 algorithm is a more sophisticated type of $TFIDF$ ranking algorithm. It's a summation over all words that make up the search term, making use of the TF calculation as well as the IDF calculation along with variables that can be used for optimisation. (Robertson et al., 2009) The version of the formula used in this project is:

$$OBM25 = \sum_{i=1}^{n} IDF(w_i) \cdot \frac{TF(w_i) \cdot (k_1 + 1)}{TF(w_i) + k_1 \cdot \left(1 - b + b \cdot \frac{W}{W_a}\right)} \tag{5.1}$$

with the optimisation variables set as $k_1 = 1,2$ and $b = 0,75$ since no advanced optimisation was considered and

- $OMB25$ is the Okapi BM 25 score
- A search term w consists of individual words $w_1, w_2, ..., w_n$

- $IDF(w_i)$ is the inverse document frequency score applied to the word w_i
- $TF(w_i)$ is the term frequency score applied to the word w_i
- W is the number of words on the website
- W_a is the average number of words on a website

5.1.2 Technical Description

As the Okapi BM25 algorithm makes use of both the TF and the $TFIDF$ calculations, these objects were stored as fields in the `OkapiBM25Score` class in a similar manner to what was done for the `TFIDFScore` class. The optimisation constants and the average document length were set as static fields. Two helper methods were added:

- `setAverageDocLength` calculates the mean number of words per website based on the websites in the index
- `okapiScore` is a recursive method to perform the summation of all the individual scores of all the words in the search query to return to the `getScore` method

5.1.3 Testing Considerations

The mathematical correctness of the OBM25 score calculations were verified using unit tests, which can be found in the ScoreTest.java file alongside the unit tests for the other `Score` classes. The set up was the same as previously mentioned in the Ranking Algorithm's chapter. Positive tests for single word and multi word query tests were constructed in the following manner:

- the word doesn't occur on the specified website
- the word doesn't occur in the website index at all
- the word occurs once on the specified website
- the word occurs once on the specified website and at least one other website
- the word occurs more than once on the specified website
- multi-word query: words don't occur on the specified website

- multi-word query: words occur once on the specified website
- multi-word query: words occur more than once on the specified website
- multi-word query: words occur once on the specified website and at least one other website
- comparison of the above score values

Negative testing consideration were harder to formulate. The most obvious to test would be dividing by 0, however as seen in equation 5.1, it's not actually possible for the denominator to be 0 due to the optimisation variables: either $TF(w_i)$ or $\frac{W}{W_a}$ has to be negative, which is not possible. To that end, no negative tests were considered for the `OkapiBM25` class.

5.2 Improve the Client GUI

We were given the possibility to improve the front-end of the search engine as an added task. The client side of our product consists of a set of files that dictate, among other things, the aspect of the page, implements the pieces and bits of code that will ultimately allow the user to communicate with the server and perform the searches, and arranges the results of the queries in a more user-friendly fashion.
Wireframes of graphical user interface designs can be found in the appendix. The guidelines defined by such wireframes took in consideration the "10 Timeless Commandments for Good Design", by the German industrial designer Dieter Rams. (Domingo, 2018)

- The search bar was brought to the centre of user's vision and any other information that was not related to the basic functionality of searching of websites was made smaller and away from that area:
  - "Good design makes a product useful. A product is bought to be used. It has to satisfy certain criteria, not only functional, but also psychological and aesthetic. Good design emphasises the usefulness of a product whilst disregarding anything that could possibly detract from it." (Domingo, 2018)
  - "Good design makes a product understandable. It clarifies the product's structure. Better still, it can make the product talk. At best, it is self-explanatory." (Domingo, 2018)

  - "Good design is unobtrusive. Products fulfilling a purpose are like tools. They are neither decorative objects nor works of art. Their design should therefore be both neutral and restrained, to leave room for the user's self-expression." (Domingo, 2018)
  - "Good design is honest. It does not make a product more innovative, powerful or valuable than it really is. It does not attempt to manipulate the consumer with promises that cannot be kept." (Domingo, 2018)
  - "Good design is honest. It does not make a product more innovative, powerful or valuable than it really is. It does not attempt to manipulate the consumer with promises that cannot be kept." (Domingo, 2018)
  - "Good design is as little design as possible. Less, but better – because it concentrates on the essential aspects, and the products are not burdened with non-essentials. Back to purity, back to simplicity." (Domingo, 2018)

- The colour scheme as well as the background were carefully selected to pass the impression to the user that they are searching through a big number of possibilities. What is the entity that is big and contain all of the beautiful things? — the Universe, of course.

  - "Good design is aesthetic. The aesthetic quality of a product is integral to its usefulness because products we use every day affect our person and our well-being. But only well-executed objects can be beautiful." (Domingo, 2018)

- The aspect of the graphical user interface adjusts to the size of the viewport, making the website responsive:

  - "Good design is thorough down to the last detail. Nothing must be arbitrary or left to chance. Care and accuracy in the design process show respect towards the user." (Domingo, 2018)

The files containing the code that concerns the front-end of the search engine can be found in the folder static. Here follows each of the files' description:

- index.html — This is the first file the browser reads upon accessing the root of a website hosted in any given domain. Hence it refers to what other files to read as well (such as the styling sheet). It provides written unformatted text which will be displayed on the browser, and it can also include links to other webpages.

- style.css — It is possible to style a given webpage from a given html file, but it is best practice to do in on a separate file (such as the present one). Should one build a website with several pages (which for each a separate html file is necessary), styling can become cumbersome and even result in styling inconsistencies. So this file provides a styling guide that can be used for several different pages providing consistency among all of them, and for this is only necessary to add the line of code that points to such file in the html. As it becomes obvious, in the long this practice also saves time as no more styling is required as the website grows.

- code.js — It holds the javascript code that allows for changes in the html (or even style), which will result in changes on what the user sees. Our javascript code was responsible for receiving the search term(s), sending them to the server, receiving the results of the given search, and translating them into html.

- Image files in static/img/ — Some images needed to provide the website with the desired aspect.

The basic implementation of the client GUI allowed the very basic functionality of performing a search. So the accomplished tasks in this regard will be described in the following subsections.

5.2.1 Adding content to be displayed by the html

Several aspects of the GUI were changed to improve the user's experience. We included a footer with links to ITU's website, the course page, as well as our LinkedIn profiles. Overall names of the classes and id's to be used in the styling sheet were also changed to achieve the intended design. Code was also added to include background images. Additionally, it seemed intuitive to allow the enter key to trigger a search, so such feature was implemented by including a small script in the html file.

5.2.2 Styling

All the aspect of the website was described in the style.css file. In here, virtually everything was changed, namely:

- Centering the content of the webpage;

- The aspect of every given class, id, link, as well as behaviour of certain elements when, for example, the user hovers the mouse over that specific element;
- Providing responsiveness no the website (adjusting the aspect of the content depending on the size of the viewport;
- Behaviour of the background images, where they would display as cross-faded slide show;
- Behaviour of the searchbar, where it would change its size by clicking on it.

5.2.3 Adding functionality through javascript

Changes in the javascript code, which can be found in the static/code.js, where made in order to allow for:

- Provide a different answer depending on the given different queries. The cases we accounted for were the following:
  - No query was provided;
  - The query did not provide any result;
  - The query in a number of results different than 0.
- Besides the title and the URL, the results are also accompanied by a certain number word from the given website.
- Clicking on a result will open it on a new tab (instead of the current tab).

5.3 Autocomplete

5.3.1 Task

Autocomplete is a feature that suggests possible input based on the current input in the input field in a dropdown list. One of the extensions was implementing this feature.

5.3.2 Basic Approach

The javascript sits on the client side of the search engine in the static folder in a file named `code.js`. It is responsible for the behaviour of the webpage and is one of 3 files that inform how the webpage looks and acts (the other two being `index.html` and `style.css`). As such, it is also responsible for communicating with the server to send and retrieve data. The javascript communicates with the sever using JSON. The server then parses the JSON request and sends a response back to client for it to then handle.
The JQuery UI offers an autocomplete plugin so little javascript is required to implement the feature. All that is required is to link the plugin to the input field in your HTML and then define a data source for your autocomplete feature to draw its suggestions from. The simplest way to accomplish that is to define a local array of words in your Javascript file, but this method only works for small data sizes and therefore is not suitable for implementation in a search engine. Which means that the alternative is to retrieve data from the server and use that as the source for the plugin.

5.3.3 Technical Description

Firstly, the JQuery UI plugin was implemented in the `code.js` file and linked to the input field `searchbox`. Rather than sourcing a local array, a `function(request, response)` was created as the source which makes a call to the server for data and performs some action on the response. Originally, the idea was that each character typed in the input field would trigger a call to server and a method in the `WebApplication` class which would check a list of words (built from the Index) to see whether any words contained the request term and build a list of the matches to return to the client. However, this idea would result on many calls being made to the server, which would slow down the operation of the search engine substantially. This was then revised to make a call to the server once and store the response locally as the autocomplete plugin source, and the method to return the data was revised in turn.
Next, the number of results was trimmed so that the dropdown list of suggestions didn't stretch the entire length of the page (as users should not be required to scrolled through results), and adjusted the plugin options so that results are only returned after at least 3 characters are in the input field.
Finally, the results returned matching the request term were ordered so that results beginning with the request term appeared at the top of the dropdown list of suggestions.
The styling for the plugin had to be added so as to match the styling of the rest of the webpage (colour, background etc), as well responsiveness to page resizing

5.4 WebCrawler

5.4.1 Basic Approach

In this section the flow of the Web Crawler will be explained. WebCrawler solutions contains three classes `WebCrawler`, `WebScraper` and `DocumentHelper`.

- The `WebCrawler` class contains the `main` method which will instantiate a `WebCrawler` object and start the whole crawling process. It does so by having a list of default website urls which it will use as starting point for traversing the internet. For extracting information and crawling from website to website it uses the the recursive method `fetchWebsiteRecursive` in the `WebScraper` class.;
- For each call to the method `fetchWebsiteRecursive` , the `WebScraper` will download the html page and extract or scrape its information and store it in an index file.;
- From each website the `WebScraper` will also extract all the links, and for all the links pointing to websites that it have not retrieved previously, it will recursively call the `fetchWebsiteRecursive` method giving in these new link as input. For doing the actual extraction of information, the `WebScraper` make use of the helper class `DocumentHelper` class;
- `DocumentHelper` contains helper methods that can extract information from a given url address. It does so by utilizing a java library `org.jsoup.Jsoup` LINK. The Jsoup library will download a html document and parse it into a data structure which can be queried for specific html tags.

5.4.2 Technical description

This section takes a closer look at the technical solution of the Web Crawler.

- As mentioned the `WebCrawler` class contains a `main` method which instantiate an object of the `WebCrawler` itself. In its constructer it gets the `ArrayList<Sting>` of default urls to look at by calling the method `getUrlsToLookAt()`. After the object has been created the main method calls the method `crawl()`. The `crawl()` method first deletes previous Web Crawler results with `deleteFileIfExist()` method. Next it loops through the list of defaultUrls and for each of them it will get the components of the url by creating a URL object from it. From the components it will concatenate Host and Path into the String urlValue and adds this value to the HashSet<String> visitedSites. This HashSet is used for maintaining an overview of which websites have already been visited, thereby making sure the whole crawling process don't end up in an infinite loop of calling the same websites repeatedly. The HashSet<String> visitedSites and the String urlValue is now passed to the fetchWebsiteRecursive method in WebScraper class which starts the recursive crawling of the internet.

- fetchWebsiteRecursive method in WebScraper takes in the parameters String url and a HashSet visitedSites. In this method the org.jsoup.Jsoup solution is used to download the html document from the given urlValue and store it in a Document object from the same library. This object is then parsed to the extractWebsiteFromDoc method in the DocumentHelper class. In here the method of Element.getElementsByTag(String tagName) found in the org.jsoup.Jsoup library, is used to fetch the different html tags containing the values that is needed for the index file, such as the <title> and <h1-3> tags. For example for getting the title, one first get the Element object representing the <head> tag, and from that Element query for the Element representing the <title> tag. When it is obtained it is possible to get its text by calling the Element.text(). If the passed Document has valid title, the method will go on to extract the words the same way as the title. Here it is looking for all the <h1-3> tags. These header objects are then stored in the ArrayList<Element> allHeaderElements. Briefly analyzing several webpages, it became apparent that content of the websites is stored in the headers of the html documents, and for this initial version of the Web Crawler it has been found sufficient to start by using only a few headers. The method continues by selecting the words to store in the ArrayList<String> words by looping through the ArrayList<Element> allHeaderElements. If the header tag contains text and has child nodes, then another forEach loop is having a look at those childNodes and take only those that are TextNodes, leaving out links and deeper level elements. Each text in the header is then split by space in order to get the individual words. Each word is then added to the ArrayList<String> words after it has been sent to cleanWord method where punctuation are removed. This process continues till all the headers have been checked and all the words added to the words collection. At the end it then uses the title and words collection to create a new object of type Website which is returned back to the WebScraper.

- The Website object created by the extractWebsiteFromDoc method is passed over to the AppendSiteToFile method in WebScraper class. Website is appended to the file `data_real_data_file.txt` in a format that integrates this data set to fit with the rest of the program.

- After the `AppendSiteToFile` method has finished the `WebScraper` class continue with extracting links from the current html document. It does so by again using a method in the `DocumentHelper` class called `extractLinksFromDoc`. This method returns an Elements collection which contains all the link Element objects. The `WebScraper` then loops over these links, and if a link is valid and not already in the `HashSet<String> visitedSites`, recursively parse it to the `fetchWebsiteRecursive` method and also add it in the `visitedSites`, thereby traversing to the next website and execute the whole process again. If the recursive call finish, it will go all the way back to the `WebCrawler` class and fetch the next default url and recursively start from there.

5.4.3 Testing

To ensure that the functionality of the `WebCrawler` is doing as intended, basic unit tests have been created which test that the correct information is extracted from a html document. For this purpose a test html document with a title, some links and few words has been setup in the unit test class `WebCrawlerTest`. This unit test class contains the following test methods:

- `correctTitle();`
- `correctNumberOfWords();`
- `correctUrl();`
- `correctNumberOfLinks().`

The unit test `correctNumberOfWords` reviled that the initial functionality of the `WebCrawler` was not handling the <h1-3> tags correctly if they contained other tags besides the text. This led to changes in the code, so it now loops through the child tags of a <h1-3> tag, and only extracting words from child if it is in a text format. Using the `org.jsoup.Jsoup` library, it means that only words from a child node of type TextNode are extracted.

5.4.4 Reflection and considerations

There are several adjustments that became apparent after trying to run the WebCrawler. Example, program could be optimized in a way that WebCrawler would disregard links that lead to information that do not distinguish and is not particularly interesting, like contact, login or links to webpages that contains information about the companies that provide technical support to the webpage erc. Large web crawlers like used by Google, are more likely to be interested to reach out to everything available on the internet, however one developing their own web crawler would consider to limit the search due to limited resources, like memory or time. The Web Crawler is retrieving websites recursively and first goes as far as it can from the initial website and starts to return back once it is not possible to go any further (there are no more links on the website reached). In the dataset that was created over running Web Crawler for little under six hours, once it 'left' the first default url homepage it never returned back to fetch the second default link. There are different ways to optimize the Web Crawler, depending on the use case. One cold be interested in a specific domains, like hotels, airline information and could restrict web crawler to search information only in the domains of interest by not letting it traverse away from the default host domains. If one would be interested to crawl specific websites, the html documents of these websites could be analyzed, to understand where the information one is looking for is located, instead of the current setting, where the WebCrawler is only looking for information located in <h1-3> tags.

Appendix A

Tables

On the following pages the tables used in this project can be found.

Table A.1: Coverage table of the parseFile(String filename) method

Choice	**Input property**	**Input data set**
1 catch	incorrect file name	A
1 try	file name	B
2 while: zero times	empty file	B1
2 while: once	file has one line	B2
2 while: more than once	file has two lines	B3
2 while: more than once	file has at least three lines	B4
3 true	the line contains a web url	B3, B4
3 false	the line does not contain a web url	B1, B2
4 true	either the listOfWords field or the title field is null	B3, B4
4 false	both the listOfWords and the title fields are not null	B4
5 true	the url field is not null	B4
5 false	the url field is null	B3, B4
6 true	the line contains a website title	B3, B4
6 false	the line doesn't contain a website title	B2
7 true	listOfWords is null	B2, B4
7 false	listOfWords is not null	B4

Table A.2: Expectancy table of the JUnit tests

Input data set	Input data	Expected output	Actual output
B1	"data/test-file1.txt"	returns an ArrayList<website>, size() == 0	returns an ArrayList<website>, size() == 0
B2	"data/test-file2.txt"	returns an ArrayList<website>, size() == 0	returns an ArrayList<website>, size() == 0
B3	"data/test-file3.txt"	returns an ArrayList<website>, size() == 0	returns an ArrayList<website>, size() == 1
B4	"data/test-file-errors.txt"	returns an ArrayList<website>, size() == 2	returns an ArrayList<website>, size() == 2
B4	"data/test-file4.txt"	returns an ArrayList<website>, size() == 2	returns an ArrayList<website>, size() == 2

Table A.3: Data Set

data/test -file2.txt	**data/test-file3.txt**	**data/test-file4.txt**	**data/test-file-errors.txt**
word3	http://example.com Title1	*PAGE:http://page1.com Title1 word1 word2 *PAGE:http://page2.com Title2 word1 word3	word1 word2 *PAGE:http://page1.com Title1 word1 word2 *PAGE:http://wrong1.com Title1 *PAGE:http://wrong2.com *PAGE:http://wrong3.com Titleword1 Titleword2 *PAGE:http://page2.com Title2 word1 word3

Appendix B

Images

On the following pages the pictures relevant to this project can be found.

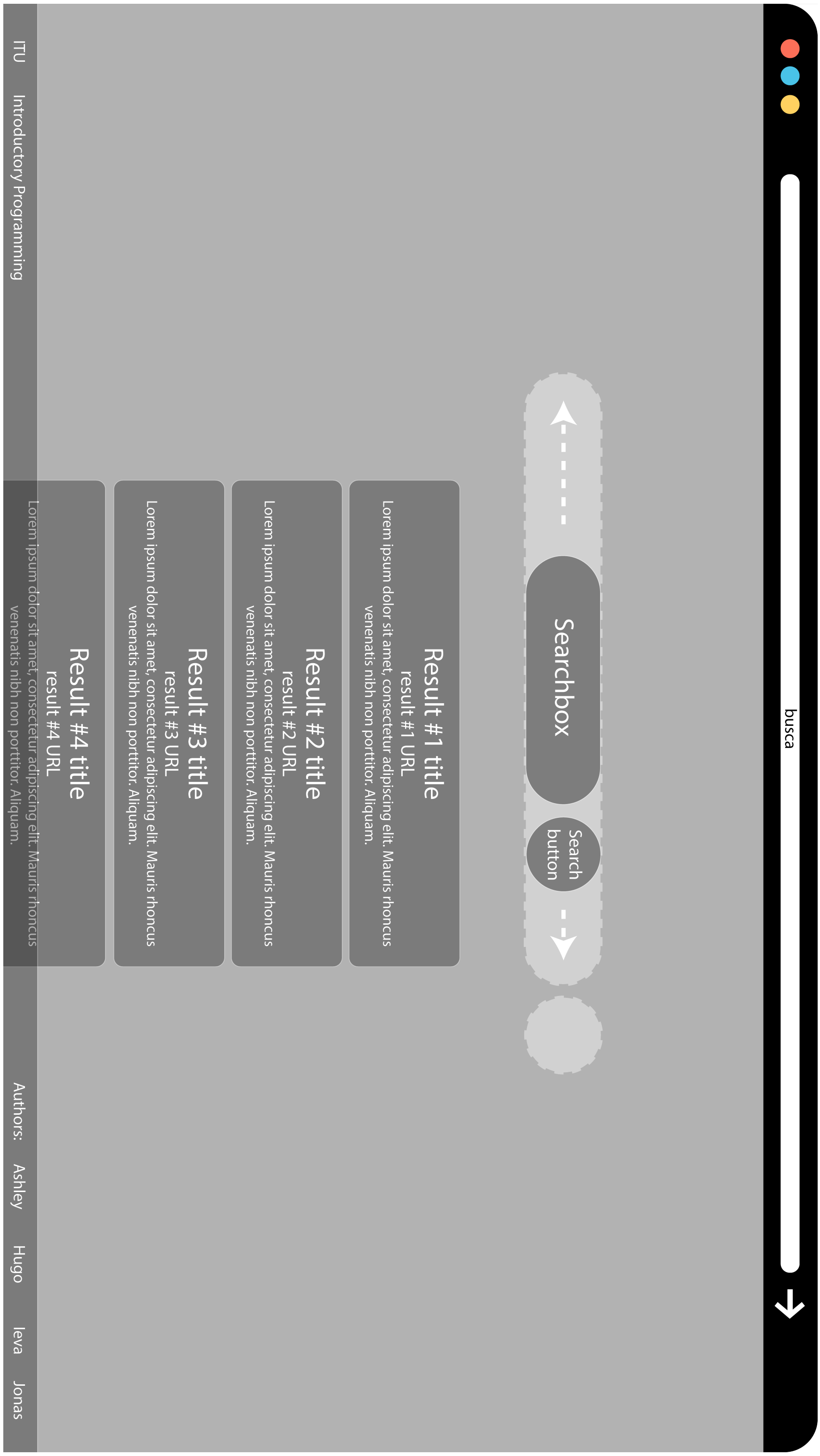
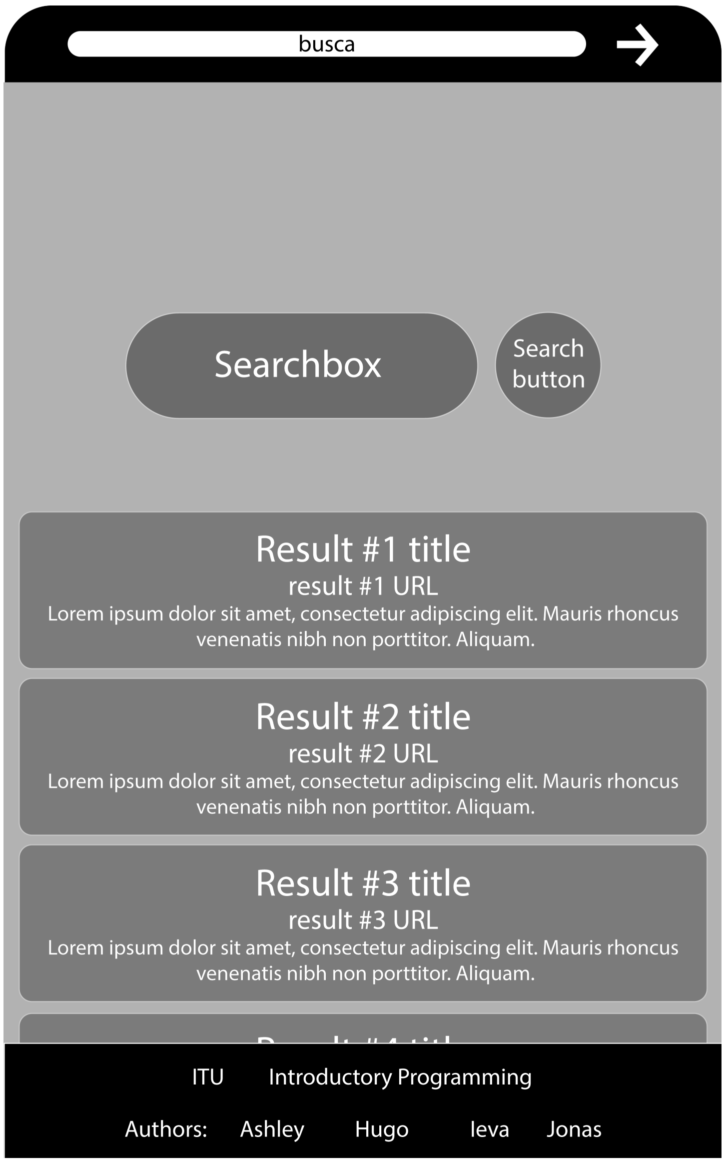


Figure B.1: Wireframe for web browser

Figure B.2: Wireframe for mobile devices



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