Math 343 - Final Project

Word Frequency Counting Optimization in Java

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Introduction

The purpose of this experiment is to test the performance of a word counting program in Java[1]. The word counting program takes as input a buffer size, algorithm type, and input file.

We are interested in the time efficiency of the operation, which will be measured as the response variable. This variable, the time taken to complete the algorithm in milliseconds, will be recorded for each run of the experiment.

Design

The experiment is a 2^k factorial design, where $k = 3$. Each experiment will be run with a replication of $n = 1000$, meaning each factor level combination will be ran 1000 times. This is a balanced design, as each factor-level combination has an equal number of observations.

Factors

1. **Factor A: Buffer Size,** this is the amount of data the program will read from the file at once. The levels for this factor are 16 bytes and 4096 bytes.
2. **Factor B: Algorithm,** this is the specific approach used to perform the word frequency count. We have two levels for this factor, which are the Hash Map approach and the Sorting approach.
3. **Factor C: Input File,** this factor corresponds to the Input File that the program will process. We have 2 levels for this factor, which are Bible.txt (4.4 MB), and pride_and_prejudice.txt (757 KB)

Given that we have 3 factors each with 2 levels, we have a total of 8 treatment combinations. We plan to collect a sample size of 1000 for every treatment combination, resulting in a total of 8000 runs for the experiment.

Response

The response of the experiment is the time in seconds that the program took to execute. Seconds were recorded to 4 significant digits. The java code for the calculation is:

```
totalTimeInSeconds = (endTime - startTime) / 1000.0;
```

Where `startTime` was set before the algorithm was run, and `endTime` was set directly after.

Procedure

Listing 1: A Sample test.txt file.

```
This is a test for the ability of the word frequency count program
This is a test
```

Listing 2: A Sample invocation of the WordFrequencyCounter.java program

```
> java WordFrequencyCounter.java 16 sorting test.txt false
This: 2
a: 2
ability: 1
count: 1
for: 1
frequency: 1
is: 2
of: 1
program: 1
test: 2
the: 2
word: 1
Total time: 0.0070 seconds.
```

[1]See Java Code in the Appendix.

Listings 1 and 2 show a sample text file and a sample invocation of the program. From these listing we can see that the the program ran with a buffer size of 16, using the "sorting" algorithm, on test.txt. The final argument "false", indicates whether or not the program should run in silent mode and not print the results. Finally we see that the program took `0.0070` seconds to run in total.

The WordFrequencyCounter.java program was run multiple times with the help of a Python program[2]. The program run_java_experiments.py takes as input the number of replicants n. It then runs the program n times for each treatment level combination as defined by the `combinations` array.

Listing 3: A Sample invocation of the run_java_experiments.py program

```
> python3 run_java_experiments.py 1000
Running 104/1000 replicate for combination [-1, 1, 1]:  76% | 6104/8000 [1:53:37<31:00,  1.02it/s]
```

The program took 3318.06 seconds or about 55 minutes to complete. It was run on a MacBook Pro, which has a 2.2 GHz 6-Core Intel Core i7 Processor.

The output of this program is a CSV file containing the treatment level combination and response in seconds that each invocation of the WordFrequencyCounter.java incurred. The program was run on a single computer in a single program call. Collecting the data programatically in this way ensures the validity and reduces the variability of each experiement.

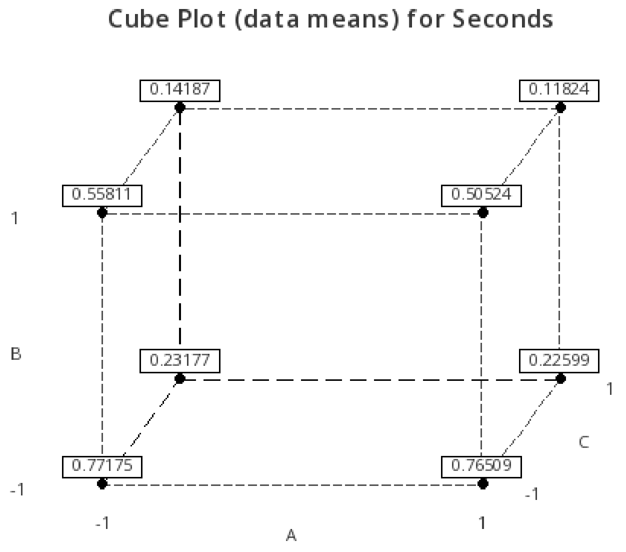


Figure 1: Cube Plot from Minitab.

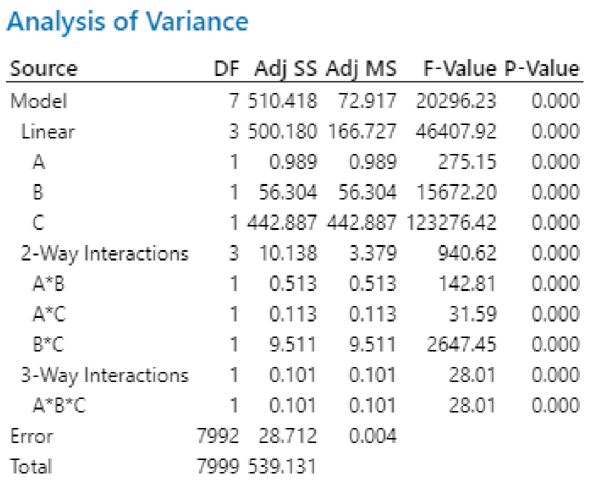
The data collected can be summarized in a cube plot. The cube plot shows the means of each treatment level combination. The Cube Plot in Figure 1 shows the means of (A) Buffer Size, (B) Algorithm, and (C) Input File, at each of the corresponding high and low levels.

[2]See Python Code in the Appendix.

Analysis of Data

Statisical analysis was performed with Minitab. The objective of the analysis was to determine what factors were significant in affecting the runtime in seconds of the computer program.

Anova Analysis of Significant Effects



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	510.418	72.917	20296.23	0.000
Linear	3	500.180	166.727	46407.92	0.000
A	1	0.989	0.989	275.15	0.000
B	1	56.304	56.304	15672.20	0.000
C	1	442.887	442.887	123276.42	0.000
2-Way Interactions	3	10.138	3.379	940.62	0.000
A*B	1	0.513	0.513	142.81	0.000
A*C	1	0.113	0.113	31.59	0.000
B*C	1	9.511	9.511	2647.45	0.000
3-Way Interactions	1	0.101	0.101	28.01	0.000
A*B*C	1	0.101	0.101	28.01	0.000
Error	7992	28.712	0.004		
Total	7999	539.131			

Figure 2: ANOVA table from Minitab.

Using the p-value from the ANOVA table in Figure 1, we can observe that each linear effect, A, B, and C, is significant at $\alpha = 0.05$. Furthermore, using the p-value, we can observe that each 2-way, and 3-way interaction is also significant at $\alpha = 0.05$.

Main and Interaction Effects

By using the standard order, and the means from the cube plot in Figure 1, we can estimate the main and interaction effects using contrast coefficients. For example, The estimated main effect of A is:

$$\begin{aligned}
\text{Est. Main Effect of A} &= \frac{1}{4}\sum_{i=1}^{8} c_i \bar{y}_i \\
&= \frac{1}{4}\left(-\bar{y}_{(1)} + \bar{y}_a - \bar{y}_b + \bar{y}_{ab} - \bar{y}_c + \bar{y}_{ac} - \bar{y}_{bc} + \bar{y}_{abc}\right) \\
&= \frac{1}{4}(-0.77175 + 0.76509 - 0.55811 + 0.50524 - 0.23177 + 0.22599 - 0.14187 + 0.11824) \\
&= -0.022235
\end{aligned}$$

Continuing using the contrast constants for a 2^3 factorial design yeilds the following table.

Effect	Estimated Main/Interaction Effect
I	0.829515
A	-0.022235
B	-0.167785
C	-0.016014
AB	0.470580
AC	0.007529
BC	0.068960
ABC	0.007090

Regression Model

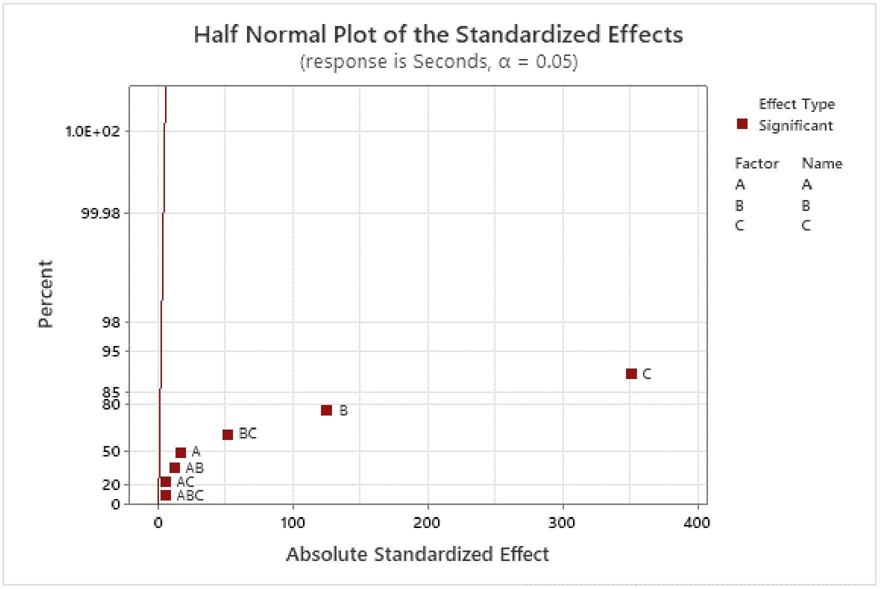


Figure 3: Half Normal Plot from Minitab.

The half normal plot in Figure 2 confirms that every factor is significant. Since each factor is significant we will not remove any variables from the model.

Regression models for 2^3 factorial designs can be described as follows.

$$E(y) = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \hat{\beta}_{12} x_1 x_2 + \hat{\beta}_3 x_3 + \hat{\beta}_{13} x_1 x_3 + \hat{\beta}_{23} x_2 x_3 + \hat{\beta}_{123} x_1 x_2 x_3$$

Where the coded variables x_1, x_2, and x_3 represent A, B, and C, respectively. The $x_1 x_2$ term is the AB interaction, and so on for the interaction terms AB through ABC. We can utilize the main and interaction effects found in section **XXX** to estimate the β parameters.

$$\begin{aligned}\hat{\beta}_1 &= \frac{\text{Main Effect of A}}{2} \\ &= \frac{-0.022235}{2} \\ &= -0.0111175\end{aligned}$$

Continuing following this logic produces the regression model:

$$E(y) = 0.41475 + -0.01111x_1 + -0.08389x_2 + -0.008x_1x_2 + 0.23529x_3 + 0.00376x_1x_3 + 0.03448x_2x_3 + 0.00354x_1x_2x_3$$

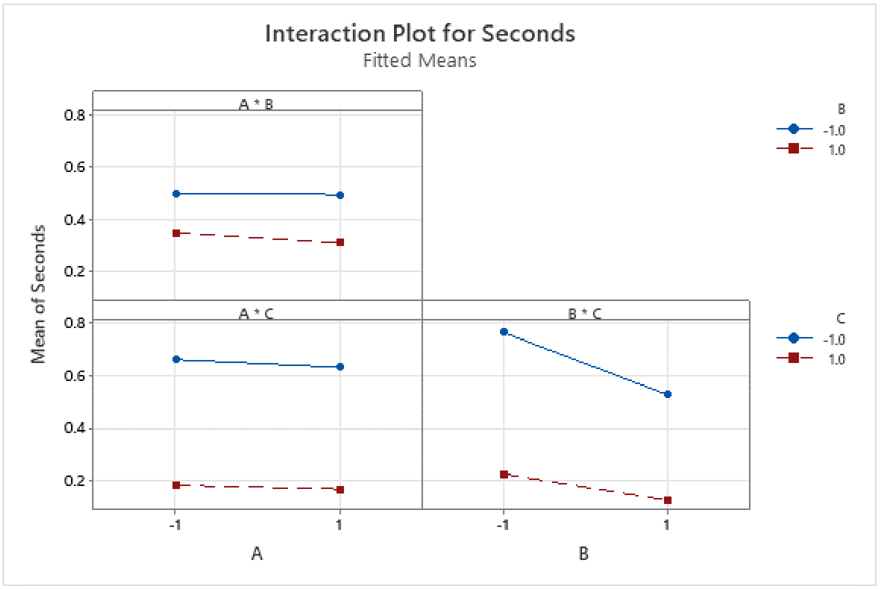


Figure 4: Interaction Plot from Minitab.

However, as we can see in Figure 3, the interaction plot would indicate that there is not 2-way interaction between the terms. This is due to the large sample size of $n = 1000$. We can observe that there does exist slight non-parallelity between the lines in the plot. This slight non-parallelity is indicative of interaction between the terms.

Residual Analysis

Conclusion

Appendix

Java Code

Listing 4: Source Code for the WordFrequencyCounter.java file.

```java
import java.io.*;
import java.nio.file.*;
import java.util.*;

public class WordFrequencyCounter {
  private static long startTime;

  public static void main(String[] args) throws IOException {
    if (args.length != 4) {
      System.err.println(
          "Usage:␣WordFrequencyCounter␣<buffer␣size>␣<algorithm>␣<input␣file>␣<quiet␣flag>");
      System.exit(1);
    }

    int bufferSize = Integer.parseInt(args[0]);
    String algorithm = args[1];
    Path inputFilePath = Paths.get(args[2]);
    boolean isQuiet = Boolean.parseBoolean(args[3]);

    if (!Files.exists(inputFilePath)) {
      System.err.println("The␣input␣file␣does␣not␣exist.");
      System.exit(2);
    }

    startTime = System.currentTimeMillis();

    switch (algorithm.toLowerCase()) {
      case "hashmap":
        hashMapApproach(inputFilePath, bufferSize, isQuiet);
        break;
      case "sorting":
        sortingApproach(inputFilePath, bufferSize, isQuiet);
        break;
      default:
        System.err.println("Invalid␣algorithm␣type.␣It␣should␣be␣’hashmap’␣or␣’sorting’.");
        System.exit(3);
    }

    long endTime = System.currentTimeMillis();
    double totalTimeInSeconds = (endTime - startTime) / 1000.0;
    System.out.printf("Total␣time:␣%.4f␣seconds.%n", totalTimeInSeconds);
  }

  private static void
      hashMapApproach(Path filePath, int bufferSize, boolean isQuiet) throws IOException {
    try (BufferedReader reader = new BufferedReader(new FileReader(filePath.toFile()), bufferSize)) {
      HashMap<String, Integer> wordCount = new HashMap<>();
      String line;

      while ((line = reader.readLine()) != null) {
        String[] words = line.split("\\s+");
        for (String word : words) {
          wordCount.put(word, wordCount.getOrDefault(word, 0) + 1);
        }
      }

      if (!isQuiet) {
        for (Map.Entry<String, Integer> entry : wordCount.entrySet()) {
          System.out.println(entry.getKey() + ":␣" + entry.getValue());
        }
      }
    }
  }

  private static void
      sortingApproach(Path filePath, int bufferSize, boolean isQuiet) throws IOException {
    try (BufferedReader reader = new BufferedReader(new FileReader(filePath.toFile()), bufferSize)) {
      ArrayList<String> wordList = new ArrayList<>();
      String line;

      while ((line = reader.readLine()) != null) {
        String[] words = line.split("\\s+");
        wordList.addAll(Arrays.asList(words));
      }

      Collections.sort(wordList);

      if (!isQuiet) {
        int count = 1;
        for (int i = 1; i < wordList.size(); i++) {
          if (wordList.get(i).equals(wordList.get(i - 1))) {
            count++;
          } else {
            System.out.println(wordList.get(i - 1) + ":␣" + count);
            count = 1;
          }
        }

        // Print the last word in the list and its count
        System.out.println(wordList.get(wordList.size() - 1) + ":␣" + count);
      }
    }
  }
}
```

Python Code

Listing 5: Source Code for the run_java_experiments.py file

```
import subprocess
import csv
import sys
from tqdm import tqdm

def main(replicants):
    # Define the mapping of parameters
    parameters = {
        'Buffer␣Size': {-1: '16', 1: '4096'},
        'Algorithm␣Type': {-1: 'sorting', 1: 'hashmap'},
        'Input␣File': {-1: 'bible.txt', 1: 'pride_and_prejudice.txt'}
    }

    # Define the combinations of parameters to run
    combinations = [
        [-1, -1, -1],
        [1, -1, -1],
        [-1, 1, -1],
        [1, 1, -1],
        [-1, -1, 1],
        [1, -1, 1],
        [-1, 1, 1],
        [1, 1, 1]
    ]

    # Prepare the CSV file
    with open('results.csv', 'w', newline='') as csvfile:
        fieldnames = ['Buffer␣Size', 'Algorithm␣Type', 'Input␣File', 'Seconds']
        writer = csv.DictWriter(csvfile, fieldnames=fieldnames)

        writer.writeheader()

        total = len(combinations) * replicants
        pbar = tqdm(total=total, ncols=120)

        # For each combination of parameters...
        for combination in combinations:
            # Repeat the experiment the desired number of times
            for i in range(replicants):
                # Prepare the arguments for the Java program
                args = ['java', 'WordFrequencyCounter.java']
                args += [parameters[fieldnames[i]][combination[i]] for i in range(len(combination))]
                args.append('true')

                # Run the Java program and capture the output
                result = subprocess.run(args, capture_output=True, text=True)

                # Extract the time value from the output
                time = float(result.stdout.split()[-2])

                # Write the result to the CSV file
                writer.writerow({
                    'Buffer␣Size': combination[0],
                    'Algorithm␣Type': combination[1],
                    'Input␣File': combination[2],
                    'Seconds': time
                })

                pbar.set_description(
                  f"Running␣{i+1}/{replicants}␣replicants␣for␣combination␣{combination}")
                pbar.update()
        pbar.close()

if __name__ == "__main__":
    main(int(sys.argv[1]))
```