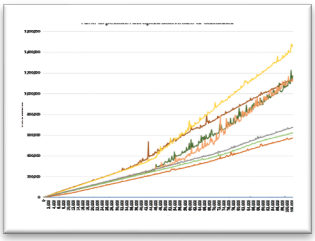
CPSC 131, Data Structures – Fall 2022
Container Review and Analysis Overview

Goals:

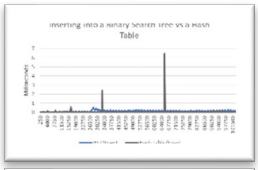
- Review and assess student's mastery of the Sequential, Associated, and Unordered data structures
- Review and assess student's mastery of using the STL's Array, Vector, List, Forward List, Map, and Unordered Map container interfaces
- Review and assess student's mastery of the similarities and differences between containers
- Review and assess student's mastery to identify the efficiency class of the fundamental operations for all the data structures covered
    - O(1), $O(\log_2 n)$, O(n), $O(n*\log_2 n)$, and $O(n^2)$
- Review and assess student's mastery of modern C++ object-oriented programming techniques

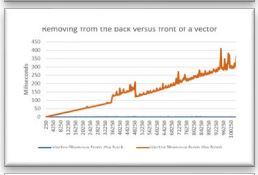
Description:

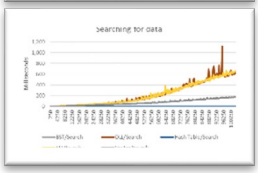
You are to perform 3 tasks, each building on the prior:



1. Complete the starter code given. Then compile and execute your program saving the output to a comma-separated value (.csv) text file. The program's output will be a table containing the amount of actual elapsed time consumed while performing an operation (columns) on a container filled with N objects (rows). Complete this task before moving on to the next.
2. Graph the program's resulting table several different ways to support the data analysis below. Complete this task before moving on to the next. Example graphs have been shown throughout the semester and some are highlighted on the right. Each graph must contain at least one operation and two data structures. Provide an overview graph, and then zoom in along one or both axis and filter to isolate interesting areas.







3. Analyze in detail the 5 items listed in your *CPSC 131 Final Exam.pdf*. For each item listed provide three to five relevant graphs and then explain the information in the graph in terms of the operation's efficiency class (Big-Oh). Talk to what you <u>see</u> on the graphs and <u>explain *why*</u> you see it. If the graphs are not what you expected, point that out and explain. Unexpected graph results may also indicate an error in your code which you may want to correct and start over. Compare and contrast the operations performed on the different data structures. Identify and describe patterns in the graphs, including peaks, trends, and variability. Provide a specific, concrete real-world example where the operation is used and then select the container best suited. Your selection should be supported by the data collected and graphed. Explain why you selected the one you did, and why you did not select the others.

Be sure to respond with well-formed grammatically correct sentences. Use only *Adobe Acrobat*[1] to fill in your *CPSC 131 Final Exam.pdf* as it has the required document layout, format, margins, font size, paragraph structure, etc. for your answers. You may not use any other tool (e.g., Google Docs) to populate the form.

You are given Operations.hpp with sections that need to be completed. This program is unusual in that it does not solve a particular problem like previous homework assignments but instead enables you to demonstrate you understand the data structures and know how to use the STL containers, their interfaces, and related iterators. Most of the sections require only a single line of code. For example, insert an object into a container at various positions (front, back, etc.). Other sections require a few more lines of code (about 5 or 6). For example, search for an object with a particular key. You've done all this before, so it should be review.

For example, given the following code fragment that measures the amount of elapsed time consumed inserting an object at the back of an unbounded vector data structure:

```
struct insert_at_back_of_vector
{
  // Function takes a constant SomeObject as a parameter, inserts that object at the back of a
  // vector, and returns nothing.
  void operator()( const SomeObject & object )
  {
    ////////////////////////// TO-DO (1) ////////////////////////////////
      /// Write the lines of code to insert "object" at the back of "my_vector"
    ////////////////////////// END-TO-DO (1) ////////////////////////////
  }

  std::vector<SomeObject> & my_vector;
};
```

you would write `my_vector.push_back( object );` in the space provided.

Be sure to submit a program that both compiles and executes with no errors and no warnings. It's better to have an incomplete section than to submit a program that does not compile clean on Tuffix using the Build.sh script. Most sections compile clean out of the box, others may require you to provide at least a return statement. A good way to start is to get your program to compile and execute clean, inserting just return statements as necessary, before solving any of the sections.

Run time tips:

As discussed all semester, when the container holds just a few objects, the efficiency class difference between data structure operations is not very interesting. It's only when you have large amounts of data in the container that the differences become very interesting.

To summarize, this program measures in nanoseconds the amount of elapsed (wall-clock) time required to perform a data structure's operation hundreds of thousands of times, each time slightly changing the container. For example, it measures the amount of time it takes to insert an object into an empty list, then the amount of time to insert an object into a list with only one object, and so on until it measures the amount of time to insert an object into a list with roughly 100,000 objects. Then it repeats for other operations and other data structures. 1 second = 1 billion (1,000,000,000) nanoseconds.

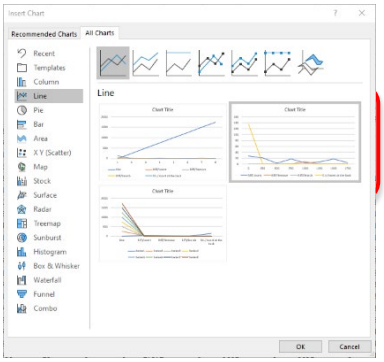
This all takes a considerable amount of time. Expect your program to take up to 15 or 20 minutes to finish execution when using the large sample data set (*-Large.dat), depending on the capabilities of your machine. To help you during development only, a smaller sample data set (*-Small.dat) is also provided but may still take a minute or two to complete. Be sure to use the large sample data set (*-Large.dat) for your final data collection, graphing, and analysis.

Graphing tips:

The program outputs comma-separated value (csv) text that you redirect to a file at the command line. Open this .csv file in a spreadsheet program, like Excel or LibreOffice Calc (do not use Google Sheets). Verify the data is placed in columns with headers and rows. Next, create a line graph within Excel[ii] by selecting all the data, including the header row, and then inserting a new line chart. For example, if your data looks like the upper right picture, select all the cells in the 5 columns and 9 rows.

Size	BST/Inser	BST/Remc	BST/Searc	DLL/Insert
0	27	0	0	135
250	21	0	0	0
500	3	0	0	0
750	17	0	0	1
1000	4	8	0	0
1250	7	0	0	1
1500	17	0	0	0
1750	5	0	0	1

Then from the Insert Tab on the ribbon, open the Insert Chart dialog and pick the line chart option as shown to the middle right.



To select which items to graph, filter away the unwanted data series as shown to the lower right.

Of course you may generate the graph locally however you wish, but it should resemble the graph in the Description above. LibreOffice Calc[iii] has similar capabilities. Do not upload data to the cloud[iv] (e.g., Google Drive, One Drive).

Rules and Constraints:

1. You are to modify only designated TO-DO sections. The grading process will detect and discard any changes made outside the designated TO-DO sections, including spacing and formatting. Designated TO-DO sections are identified with the following comments:

```
//////////////////////// TO-DO (X) ////////////////////////////////
...
//////////////////////// END-TO-DO (X) ////////////////////////////
```

   Keep and do not alter these comments. Insert your code between them. In this assignment, there are 21 such sections of code you are being asked to complete. You were given the solution to one of them above. All of them are in Operations.hpp.

2. This assignment **requires** you redirect standard input from a text file and redirect standard output to a text file. See the *I/O Redirection* and *How to Build and Run Your Programs with Build.sh* in Tom's Survival Guide in Canvas. Do not run the program from within an IDE, it may alter the times collected and provide you false data to work with. To run your program, enter:

```
program < input_data_file > output.csv
```

   where `program` is the name of your executable image file, `input_data_file` is the name of the file containing input data. If the file name contains special characters or spaces, enclose it in double quotes. For example:

```
"./project_clang++" < "My Database-Large.dat" > output.csv
```

3. Use Build.sh to compile and link your program – it employs the correct compile options.

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[i] Install Adobe Acrobat Reader on Mac OS, Install Adobe Acrobat Reader DC on Ubuntu 22.04 (i.e., Tuffix)
[ii] Search Google for "Create a line chart in Excel" for more information, how-tos, and videos. You must not use One Drive
[iii] View a *Charting Size vs Time* video tutorial to create graphs with LibreOffice Calc on Tuffix here.
[iv] Google Sheets & Docs, and Word & Excel Online produce distinctive results, are easily detectible, and must be avoided.