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Computer Science 250: Analysis of Algorithms
Laboratory Assignment 2
Experimental Verification of Runtimes

Part 1

FourSum.java	Run 1	Run 2	Run 3	Run 4	Run 5	Mean(Average)	Standard Deviation
1Kints	81.454	82.408	81.513	81.407	81.341	81.62646	0.39574662212515
2Kints	1298.131	1298.078	1298.968	1298.089	1298.506	1298.3544	0.34531990964905
4Kints	20,759.469	20,733.701	20,729.643	20,724.63	20,730.529	20,735.5944	12.287204687805

Figure 1: Table of Results of Part 1 of Laboratory Assignment (seconds)

2. Determine the runtime of this algorithm in Big-O notation, and estimate what you would expect to find using tilde notation (a detailed calculation is not necessary for this step).
Big-O Notation = $O(n^4)$
Tilde Notation/ Tilde Approximation: $\frac{n^4}{24}$

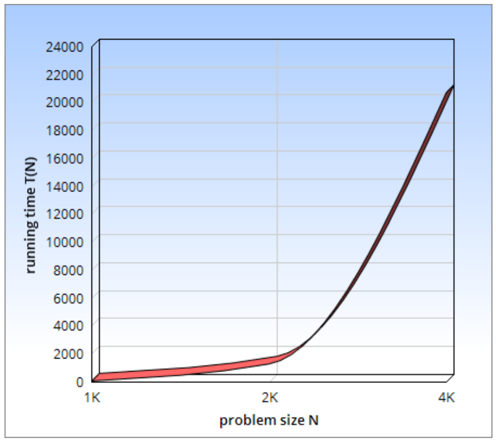
4. How long do you expect execution will take on the 2Kints.text file? Note this somewhere, as I will ask for it later.
Since 1Kints took 80 seconds, I estimate 2Kints to take 1280 seconds long

6. How long do you expect execution will take on the 4Kints.txt file?
4Kints estimated time: 20480 seconds

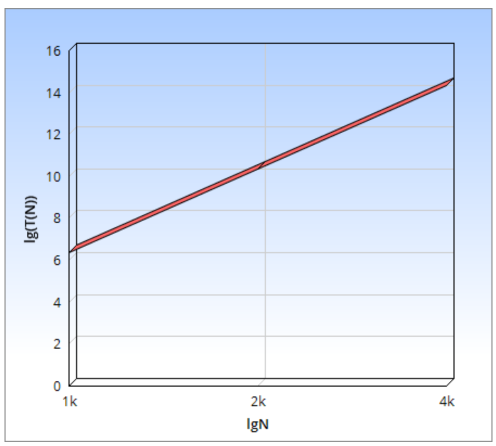
8. Is a pattern becoming apparent? How long do you expect execution will take on the 8Kints.txt file? The 16Kints.txt file? The 1Mints.txt file?
8Kints estimated time: 327680 seconds
16Kints estimated time: 5242880 seconds
1Mints estimated time: $8 * 10^{13}$ seconds

11. Create two graphs, a linear-axis graph and a log-log axis graph, showing how your mean program runtimes increased as input size increased.

Linear Axis Graph of Part 1



Log-Log axis graph of Part 1



Part 2

FourSumFast.java	Run 1	Run 2	Run 3	Run 4	Run 5	Mean(Average)	Standard Deviation
1Kints	5.177	5.149	5.157	5.154	5.146	5.1566	0.010892199043352
2Kints	45.241	45.511	44.476	45.496	44.997	45.1442	0.38362346122207
4Kints	388.047	386.84	387.791	391.895	387.39	388.3926	1.7979956173473
8Kints	3271.271	3294.607	3307.508	3288.185	3295.925	3291.4992	11.880166672231

Figure 2: Table of Results of Part 2 of Laboratory Assignment (seconds)

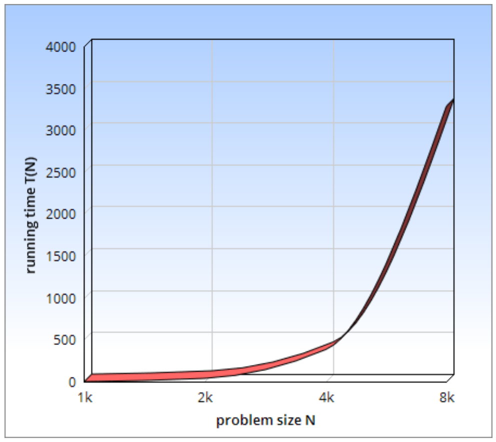
2. Determine the runtime of this algorithm in Big-O notation.
Big-O notation: $O(n^3(\log(n))$
3. How long do you expect execution will take on the 1Kints.txt file, knowing the performance that you measured with FourSum?
Knowing the performance of 1Kints on FourSum, I expect the execution to be 5 seconds.

5. How long do you expect execution will take on the 2Kints.txt file?
I expect the execution time on the 2Kints.txt file to be 50 seconds.

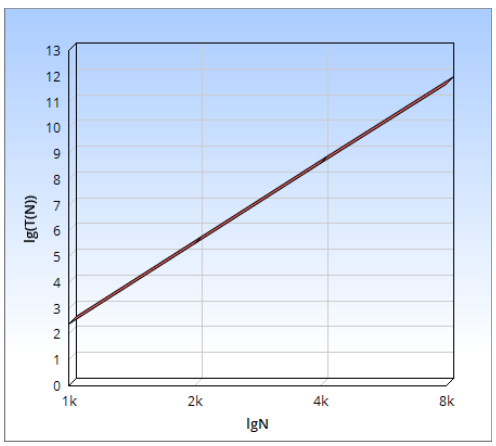
7. How long do you expect execution will take on the 4Kints.txt file?
I expect the execution time will take 320 seconds on the 4Kints.txt file

9. You should once against see the pattern emerge. How long do you expect execution will take on the 8Kints.txt file? The 16Kints.txt file? The 1Mints.txt file?
8Kints : 2560 seconds
16Kints : 20480 seconds
1Mints : $2.982894 * 10^{10}$

Linear Axis Graph of Part 2



Log-Log axis graph of Part 2



Part 3
While You Have Some Downtime

1. Consider the following code segment. Calculate its approximate runtime, in both tilde notation and in Big-O notation.

```
int sum = 0;
for (int i = 1; i < n; i *= 2) {
   for (int j = 0; j < n; j++) {
      sum++;
   }//for
}//for
```

   Big-O Notation: $O(nlog(n))$
   Tilde Notation: $2nlog(n)$

2. Sketch an algorithm that, given two sorted arrays of n int values, prints all elements that appear in both arrays, in sorted order. Show that the running time of your algorithm is $O(n)$ in the worst case.

```
int [] a; //declaring the array a
int [] b; //declaring the array b
int [] c = new int[Math.min(a.length, b.length)];
int a1 = 0;
int b1 = 0;
int c1 = 0;
while (a1 < a.length && b1 < b.length) {
   if(a[a1] < b[b1]) {
      a1++;
   } else if (a[a1] > b[b1]) {
      b1++;
   }else {
      if (c1 == 0 || a[a1] != c[c1 - 1]) {
            c[c1++] = a[a1];
         }
      a1++; b1++;
      }
   }
   return Array.copyOfRange(c, 0, c1);
}

\item What does the following recursive function return
\begin{lstlisting}
public static String mystery(String s){
   if (s.length() <= 1) {
```

```
        return s;
    }else {
        String a = a.subString(0, s.length()/2);
        String b = b.subString(s.length()/2, s.length());
        return mystery(b) + mystery(a);
    }//if-else
}//mystery
```

This recursive function will return a string in reverse order.

3. How much physical memory was taken up by the contents of the 1Kints.txt file when loaded into a one-dimensional array? The 2Kints.txt file? 4Kints.txt? 1Mints.txt? How much physical memory would be taken up if the files contained doubles rather than int? How much physical memory would be taken up if each of the file inputs were arranged in a two-dimensional array with 100 rows (1000 ints in a 100x10 array, 200 ints in a 100x20 array, etc.)? (Note: I am looking for exact numbers of bytes here, not an approximation based off of tilde notation.)
   Ints 1Kints.txt file in one-dimensional array: 1,024 bytes
   2Kints.txt file in one-dimensional array: 8,024 bytes
   4Kints.txt file in one-dimensional array: 16,024 bytes
   1Mints.txt file in one-dimensional array: 4,000,024 bytes
   If the files contained doubles instead rather than ints, then an array of n doubles would be 24 + 8n, so:
   Doubles
   1K file in one-dimensional array: 8,024 bytes
   2K file in one-dimensional array: 16,024 bytes
   4K file in one-dimensional array: 32,024 bytes
   1M file in one-dimensional array: 8,000,024 bytes
   Two Dimensional Array:
   1000 ints in a 100 x 10 array: 4000 bytes
   200 ints in a 100 x 20 array: 8000 bytes

4. As a review of working with the Stack data structure, create a file called Parantheses.java that reads in text from standard input and uses a stack to determine whether its parantheses are properly blanced. For example, your program should print true for [()]{}{[()()]()} and false for [(]).

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


public class Parentheses {
    private static final char L_PAREN = '('; //this is the
        declaration for the left parantheses (
    private static final char R_PAREN = ')'; //this is the
        declaration for the right parantheses )
```

```java
private static final char L_BRACE = '{'; //this is the
    declaration for the left brace {
private static final char R_BRACE = '}'; //this is the
    declaration for the right brace }
private static final char L_BRACKET = '['; //this is the
    declaration for the left bracket )
private static final char R_BRACKET = ']'; //this is the
    declaration for the right bracket )

public static boolean isBalanced(String s) {
    Stack<Character> stack = new Stack<Character>();
        //declartion of a stack
    for (int i = 0; i < s.length(); i++) {

        if      (s.charAt(i) == L_PAREN) stack.push(L_PAREN);
            //if a left parantheses is found, then push it to
            the top of the stack

        else if (s.charAt(i) == L_BRACE) stack.push(L_BRACE);
            //if a left brace is found, then push it to the top
            of the stack

        else if (s.charAt(i) == L_BRACKET)
            stack.push(L_BRACKET); //if a left bracket is
            found, then push it to the top of the stack

        else if (s.charAt(i) == R_PAREN) {
            if (stack.isEmpty())     return false;
            if (stack.pop() != L_PAREN) return false;
            //is the right parantheses and left parntheses
                cannot be matched, then return false
        } //if

        else if (s.charAt(i) == R_BRACE) {
            if (stack.isEmpty())     return false;
            if (stack.pop() != L_BRACE) return false;
            //if a right brace cannot be matched with a left
                brace, then return false
        } //if

        else if (s.charAt(i) == R_BRACKET) {
            if (stack.isEmpty())     return false;
            if (stack.pop() != L_BRACKET) return false;
            //if a right bracket and left bracket cannot be
                matched, then return false.
        } //if

        // ignore all other characters

    } //for
```

```java
        return stack.isEmpty();
    } //isBalanced


    public static void main(String[] args) {
        String s = StdIn.readAll();
        System.out.println(isBalanced(s)); //print line statement
             to call the method isBalanced with a string as a
             parameter
    } //main

} //Parantheses.java
```