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CT2109 Object Oriented Programming: Data Structures and Algorithms

Assignment 3: Double-base Palindromes and Complexity Analysis

Problem Statement

A program that tells the user whether the input is a palindrome or not. A palindrome reads the same forwards as it does backwards. E.g. 1010101 and 7779777 are palindromes.

The program uses multiple different methods to determine whether the input is a palindrome or not. Each method returns a Boolean that is true when the input is determined to be a palindrome. We are going to use this to run automated tests to compare the efficiency of these methods. The amount of primitive operations and time taken will be recorded for each algorithm to check the palindromes from 0 to 1000000 (1 million) for both decimal and binary numbers. At the end of the execution of the program, the user will be able to see
1. the time taken for each algorithm (decimal, binary and both added together),
2. the amount of primitive operations each algorithm made (amount of operations of the decimal and binary checking added together)
3. the amount of instances where both the decimal and binary equivalent of a number are palindromic

The step count method will be used for time complexity analysis.

The number of operations will be plotted against the size of the problem using Excel to allow a visual comparison of the time complexity between the different palindrome checking algorithms. This is equivalent to plotting a graph of the current total primitive operations against some amount of numbers checked. Data for this will be collected by displaying the current primitive operation counts every 50000 numbers checked.

Analysis and Design Notes

<u>Method 1 – String Equals</u>
isPalindromeStringEquals(String input)
For the length of the String, starting from the last index, append the charAt that location of the input a new String called reversed.

If input equals reversed, using the .equals method, then the input is a palindrome so return true; else the input is not a palindrome so return false.

<u>Method 2 – Character By Character</u>

isPalindromeCharacterByCharacter(String input)

Compare the first and the last characters

If they are equal then keep comparing

If at the end they are all equal then the input is a palindrome

If at any point the characters are not equal then it is not a palindrome.

If an input of length 1 is input then just return true.

Need to know how many times to loop when comparing

Figuring this out…

The example input is: 1221

Length: 4

Even length

4/2 = 2

Compare the first 2 with the last 2

Compare length/2 forward to backward

Loop duration is length/2

Now the example input is 12321

Length: 5

Odd length

(4-1)/2 = 2

Compare the first 2 with the last 2

Compare (length-1)/2 forward to backward

Leave the middle one alone because it is equal to itself

<u>Method 3 – Stack Queue</u>

isPalindromeStackQueue(String input)

Basic idea:

Place the input into both a stack and queue. If the input is a palindrome, the first character popped from the stack will be the same as the first character dequeued, and so on for the second and subsequent characters until the stack and queue are empty. This works because a Stack is LIFO “last in first out” and a queue is FIFO “first in first out.”

Pseudocode:

Create a stack and a queue

For each character in the input string, push that character to the stack and queue that character

While the stack is not empty, check that what you pop from the stack matches what you dequeue from the queue: if they match, do nothing, else: return false (then it is not a palindrome)

Return true; (will get to this if all characters popped and dequeued match each other)

Method 4 – Recursion Reverse

isPalindromeRecursionReverse(String input)

This method uses a utility method called **reverse()**:

String reverse(String input)

Example input string “abcde”

We want reverse() to return “edcba”

Using recursion:

Function call:	input.length():	New call: reverse(input without the last character)
1: reverse(“abcde”)	5	bcde
2: reverse(“bcde”)	4	cde
3: reverse(“cde”)	3	de
4: reverse(“de”)	2	e
5: reverse(“e”)	1	[Base case reached, start returning values]

Function call:	returns:	
5: input = e	e	e
4: input = de	e + input.substring(0, 1)	ed
3: input = cde	ed + input.substring(0, 1)	edc
2: input = bcde	edc + input.substring(0, 1)	edcb
1: input = abcde	edcb + input.substring(0, 1)	edcba

Note function call 1 has “abcde” stored in the input variable. It didn’t send “a” to any reverse call. Function call 1 appends the “a” after all of the reverse calls return their values.

The returned value of function call 1 is “edcba” which is the reverse of the input “abcde”.

Back to method 4: isPalindromeRecursionReverse(String input)

Use the reverse function to get a reversed String of the input.

If the reverse String is equal to the input String, then the input is a palindrome.

Decimal to binary String utility method:

public String decimalToBinary(String decimal)

Input = decimal as a String

Output = converted binary as a String

Convert the decimal String into an int - Using: Integer.parseInt(decimal)

Then convert the int to a binary String - Using: Integer.toBinaryString()

return Integer.toBinaryString(Integer.parseInt(decimal));

Main method

Firstly test that the decimal to binary method works

Begin palindrome checking
Going to do 3 runs…. (to get an accurate reading of time taken)
FOR 3 RUNS
{
I am going to loop through numbers 0 to 1000000
Start of Looping 0 to 1000000
On each iteration of the loop I am going to
- output the current primitive operation counts every 50000 iterations (used for csv file for graph)
- get a String for the current number (decimal)
- get a String for the current number using my decimalToBinary method (binary)
then for all 4 palindrome methods I am:
- grabbing the current system time in milliseconds as the "start time"
- performing the method
- adding the time elapsed (current time - start time) to a variable that tracks the total time spent for a particular method using Binary or Decimal inputs
(ie. in total there are 8 timers: 1 for binary, 1 for decimal for the 4 different methods)
- Also note that within each method there are statements that increment a global primitive operation counter. There will be 4 counters in total, one for each method. The counter is, therefore, the sum of the primitive operations for palindrome checks for the binary and decimal numbers.
- the variable (we will call is instancesPalindromicBothBases) that tracks the number of times that a number is palindromic in both binary and decimal, is incremented. This is done by storing the boolean result of one of the methods for both decimal and binary. If both the decimal and binary booleans are true, then increment the counter. Set the booleans to false for the next iteration.
End of Looping 0 to 1000000

Reset counters for next run

}

Code

```
public class Palindrome
{
   //Primitive operation counters for each of the palindrome detecting methods
   //Variables for keeping track of time taken
   private static int stringCount = 0;
   private static long stringTime = 0;
   private static long stringTimeBinary = 0;
   private static int characterCount = 0;
   private static long characterTime = 0;
   private static long characterTimeBinary = 0;
   private static int stackQueueCount = 0;
   private static long stackQueueTime = 0;
   private static long stackQueueTimeBinary = 0;
   private static int recursiveCount = 0;
   private static long recursiveTime = 0;
   private static long recursiveTimeBinary = 0;
   private static int instancesPalindromicBothBases = 0;

   public static void main(String[] args) {
      //Create a test object
      Palindrome t = new Palindrome();

      int decimal = 21;
      System.out.println("Decimal to binary String test");
      System.out.println("==============================================");
      System.out.println("Decimal: " + decimal);
      System.out.println("Binary: " + t.decimalToBinary(String.valueOf(decimal)));
      System.out.println("End of decimal to binary String test");
      System.out.println("==============================================");
```

```
        String input = "";
        String inputBinary = "";

        //My test code for individual functions
//      //Use method 1
//      boolean stringEqualsPalindrome = t.isPalindromeStringEquals(input);
//
//      //Use method 2
//      boolean characterByCharacterPalindrome = t.isPalindromeCharacterByCharacter(input);
//
//      //Use method 3
//      boolean stackQueuePalindrome = t.isPalindromeStackQueue(input);
//
//      //Use method 4
//      boolean recursionReversePalindrome = t.isPalindromeRecursionReverse(input);
//
//      if(characterByCharacterPalindrome)
//      {
//          System.out.println(input + ": is a palindrome");
//      }
//      else
//      {
//          System.out.println(input + " is not a palindrome");
//      }

        //Check the numbers 0-1000000 for palindromes in binary and decimal
        //Do this three times to get an accurate reading of time taken

        System.out.println("\n\nInitiating palindrome testing...");
        for(int r = 1; r <= 3; r++)
```

```
    {
        System.out.println("\nRun " + r);
        System.out.println("================================================");
        System.out.println("CSV data, paste into excel\n");

        //Loop through every number from 1 including 1000000
        long start = 0;
        boolean isPalindromeDecimal = false;
        boolean isPalindromeBinary = false;

        for (int i = 0; i <= 1000000; i++) {
            //Generate CSV
            //Note: CSV data counts primitive operations for both the decimal and binary number together
            //Every 50000th number, display the current operation counts
            //Note: the last value (1000000) will not be included in this csv data
            //because we are checking 1000001 numbers.
            //1000001 numbers do not fit into a graph if we divide the graph into ranges of 50000
            if (i % 50000 == 0) {
                System.out.println(i + "," + stringCount + "," + characterCount + "," + stackQueueCount + "," + recursiveCount);
            }

            //Get the next number to be checked
            input = String.valueOf(i);

            //Get the binary of that number
            inputBinary = t.decimalToBinary(input);

            //Running the algorithms for the current number
            //Use each algorithm on both the decimal and binary number
            //Every time an algorithm is called, calculate the amount of time it takes to run it
```

```
//and add that time to a variable that is keeping track of its total time taken

//StringEquals method
//Decimal
start = System.currentTimeMillis();
isPalindromeDecimal = t.isPalindromeStringEquals(input);
stringTime += System.currentTimeMillis() - start;
//Binary
start = System.currentTimeMillis();
isPalindromeBinary = t.isPalindromeStringEquals(inputBinary);
stringTimeBinary += System.currentTimeMillis() - start;

//CharacterByCharacter method
//Decimal
start = System.currentTimeMillis();
isPalindromeDecimal = t.isPalindromeCharacterByCharacter(input);
characterTime += System.currentTimeMillis() - start;
//Binary
start = System.currentTimeMillis();
isPalindromeBinary = t.isPalindromeCharacterByCharacter(inputBinary);
characterTimeBinary += System.currentTimeMillis() - start;

//StackQueue method
//Decimal
start = System.currentTimeMillis();
isPalindromeDecimal = t.isPalindromeStackQueue(input);
stackQueueTime += System.currentTimeMillis() - start;
//Binary
start = System.currentTimeMillis();
isPalindromeBinary = t.isPalindromeStackQueue(inputBinary);
stackQueueTimeBinary += System.currentTimeMillis() - start;
```

```
            //RecursionReverse method
            //Decimal
            start = System.currentTimeMillis();
            isPalindromeDecimal = t.isPalindromeRecursionReverse(input);
            recursiveTime += System.currentTimeMillis() - start;
            //Binary
            start = System.currentTimeMillis();
            isPalindromeBinary = t.isPalindromeRecursionReverse(inputBinary);
            recursiveTimeBinary += System.currentTimeMillis() - start;

            //How many instances is a number palindromic in both bases?
            //If this current number is palindromic in both bases, increment
instancesPalindromicBothBases
            //Note: the assignment of isPalindromeDecimal and isPalindromeBinary is repeated
throughout
            //the methods so that the time of one of the algorithms isn't more affected
            if (isPalindromeDecimal && isPalindromeBinary) {
               instancesPalindromicBothBases++;
            }

         }

         System.out.println("\nResults for run " + r);
         System.out.println("----------------------------------------");
         System.out.println("Time taken for 0-1000000 (decimal only)");
         System.out.println("----------------------------------------");
         System.out.println("String Equals:\t\t\t" + stringTime + "ms");
         System.out.println("Character by Character:\t" + characterTime + "ms");
         System.out.println("Stack Queue:\t\t\t" + stackQueueTime + "ms");
         System.out.println("Recursion Reverse:\t\t" + recursiveTime + "ms");
         System.out.println("----------------------------------------");
```

```
        System.out.println("Time taken for 0-1000000 (binary only)");
        System.out.println("---------------------------------------");
        System.out.println("String Equals:\t\t\t" + stringTimeBinary + "ms");
        System.out.println("Character by Character:\t" + characterTimeBinary + "ms");
        System.out.println("Stack Queue:\t\t\t" + stackQueueTimeBinary + "ms");
        System.out.println("Recursion Reverse:\t\t" + recursiveTimeBinary + "ms");
        System.out.println("---------------------------------------");
        System.out.println("Time taken for 0-1000000 (total of decimal and binary)");
        System.out.println("---------------------------------------");
        System.out.println("String Equals:\t\t\t" + (stringTime + stringTimeBinary) + "ms");
        System.out.println("Character by Character:\t" + (characterTime + characterTimeBinary) +
"ms");
        System.out.println("Stack Queue:\t\t\t" + (stackQueueTime + stackQueueTimeBinary) +
"ms");
        System.out.println("Recursion Reverse:\t\t" + (recursiveTime + recursiveTimeBinary) + "ms");
        System.out.println("---------------------------------------");
        System.out.println("Primitive operations for 0-1000000 (total of decimal and binary)");
        System.out.println("---------------------------------------");
        System.out.println("String Equals:\t\t\t" + stringCount + " primitive operations");
        System.out.println("Character by Character:\t" + characterCount + " primitive operations");
        System.out.println("Stack Queue:\t\t\t" + stackQueueCount + " primitive operations");
        System.out.println("Recursion Reverse:\t\t" + recursiveCount + " primitive operations");
        System.out.println("---------------------------------------");
        System.out.println("Instances both bases palindromic for 0-1000000");
        System.out.println("---------------------------------------");
        System.out.println("Palindromic in both bases in: " + instancesPalindromicBothBases + "
instances");
        System.out.println("---------------------------------------");
        System.out.println("End of run " + r);
        System.out.println("================================================\n");
        //End of a run
        //Reset all variables
```

```
        stringTime = 0;
        characterTime = 0;
        stackQueueTime = 0;
        recursiveTime = 0;
        stringTimeBinary = 0;
        characterTimeBinary = 0;
        stackQueueTimeBinary = 0;
        recursiveTimeBinary = 0;
        stringCount = 0;
        characterCount = 0;
        stackQueueCount = 0;
        recursiveCount = 0;
        instancesPalindromicBothBases = 0;
    }
    //End of all runs
    System.out.println("All runs complete");
}

public Palindrome()
{

}

public boolean isPalindromeStringEquals(String input)
{
    String reversed = "";
    stringCount++;

    //Reverse the string using loop
    //Count the initialization of i to the length() function
    stringCount = stringCount + 2;
```

```
    for(int i = input.length()-1; i >= 0; i--)
    {
        //Count loop condition and i--
        stringCount = stringCount + 2;

        stringCount = stringCount + 3;
        reversed += input.charAt(i);
    }
    //The last evaluation of the conditional statement is false and the loop doesn't run
    stringCount++;

    //Examined String.java and StringLatin1.java to count primitive operations of equals
    //Counted equals to have 7 + 1 + 5*input.length() + 1 + 1 primitive operations
    stringCount = stringCount + (10+(5*input.length()));
    if(input.equals(reversed))
    {
        stringCount++;
        //The input is a palindrome
        return true;
    }
    else
    {
        stringCount++;
        //The input is not a palindrome
        return false;
    }
}

public boolean isPalindromeCharacterByCharacter(String input)
{
    //An input of length 1 is a palindrome
```

```
        characterCount = characterCount + 2;
        if(input.length() == 1)
        {
            characterCount++;
            return true;
        }

        //This method compares the first character to the last and keeps comparing, moving towards the centre
        //If the input is odd, then we don't need to compare the middle item to anything
        //121 is a palindrome
        //The length is 3
        //We would compare the first and last, 1 == 1.
        //Don't have anything to compare the middle item to
        //All comparisons were equal: therefore 121 is a palindrome

        //Find the amount of times we need to compare characters
        int i = 0;
        int length = input.length();
        characterCount = characterCount + 3;
        if(length % 2 == 0)
        {
            characterCount = characterCount + 2;
            i = length / 2;
        }
        else
        {
            characterCount = characterCount + 3;
            i = (length - 1) / 2;
        }
```

```
    //Compare first and last letters
    //if any of the comparisons are not equal, then the input is not a palindrome
    characterCount++;
    for(int j = 0; j<i; j++)
    {
        //Count loop condition and i++
        characterCount = characterCount + 2;

        //old code if needed: (input.charAt(j)+"").equals(input.charAt(length-j-1)+"")
        characterCount = characterCount + 4;
        if(input.charAt(j) == input.charAt(length-j-1))
        {
            //All good, the characters are equal, so far the input is a palindrome
        }
        else
        {
            characterCount++;
            return false;
        }
    }
    //The last evaluation of the conditional statement is false and the loop doesn't run
    characterCount++;

    characterCount++;
    return true;
}

public boolean isPalindromeStackQueue(String input)
{
    //Create a stack
    Stack s = new ArrayStack(20);
```

```
//ArrayStack constructor has 2 time steps in it
stackQueueCount = stackQueueCount + 2;



//Create a queue
Queue q = new ArrayQueue(20);
//ArrayQueue constructor has 2 time steps in it
stackQueueCount = stackQueueCount + 2;

//Add each character to both stack and queue as it is read
//Count the initialization of i
stackQueueCount++;
for(int i = 0; i < input.length(); i++)
{
   //Count loop condition and i++
   stackQueueCount = stackQueueCount + 2;

   //Push() takes 5 operations
   //1 for if
   //2 for isFull()
   //1 for top++
   //1 for assigning the element to the top index of the array
   s.push(input.charAt(i));
   //charAt(i) is 1 primitive operation
   stackQueueCount = stackQueueCount + 6;

   //Enqueue() takes 5 operations
   //2 for isFull()
   //1 for rear++
   //2 for Q[rear] = n
   q.enqueue(input.charAt(i));
```

```
    //charAt(i) is 1 primitive operation
    stackQueueCount = stackQueueCount + 6;
}
//The last evaluation of the conditional statement is false and the loop doesn't run
stackQueueCount++;

//For calculating dequeue()'s primitive operations
int r = (input.length() - 1);

//Compare characters from stack and queue
while(!s.isEmpty())
{
    //1 primitive operation per isEmpty()
    stackQueueCount++;

    //Counting pop()'s primitive operations
    // Object element; +1
    // isEmpty() +1
    // element = S[top]; +2
    // S[top] = null; +2
    // top--; +1
    // return element; +1
    // pop() takes 8 primitive operations

    //Counting dequeue()'s primitive operations
    // isEmpty() +2
    // Object toReturn = Q[0]; +2
    // int i = 1; +1
    // while loop:
    // r+1 "while condition"
```

```
        // + r "i-1 calculation" + r "access array" + r "access array" + r "assignment" + r "i++
calculation")
        // rear--; calculation +1
        // That is: 6r + 7
        // r is initially equal to the length of the string -1,
        // because rear is equivalent to the amount of items in the ArrayQueue
        // and r is decremented every iteration of this while loop,
        // because an item is dequeued at every iteration

        //Add the primitive operations of the dequeue() function for this iteration
        if(r >= 1)
        {
           stackQueueCount = stackQueueCount + r * 6 + 7;
        }
        r--;

        //Add the primitive operations of the pop() function for this iteration
        stackQueueCount = stackQueueCount + 8;

        //primitive operation for if condition
        stackQueueCount++;
        //old code in case I need it again: if((""+s.pop()).equals(q.dequeue()+""))
        if(s.pop() == q.dequeue())
        {
           //Character at the front matches character at the back
           //Currently, still a palindrome
        }
        else
        {
           //Character at the front does not match character at the back
           //input is not a palindrome
```

```
            stackQueueCount++;
            return false;
        }
    }

    //Checked every letter
    //input is definitely a palindrome
    stackQueueCount++;
    return true;
}

//Returns a reversed String of the input string
public String reverse(String input)
{
    recursiveCount = recursiveCount + 2;
    //Base case
    if(input.length() == 1)
    {
        recursiveCount++;
        return input;
    }

    recursiveCount = recursiveCount + 4;
    //Reduction step is when the function is called by sending the string without the first letter
    //Reduction: reverse(input.substring(1,input.length()))
    return reverse(input.substring(1,input.length())) + input.substring(0, 1);
}

public boolean isPalindromeRecursionReverse(String input)
{
    recursiveCount++;
```

```
        //Get the reversed string using recursion
        String reverse = reverse(input);

        //Examined String.java and StringLatin1.java to count primitive operations of equals
        //Counted equals to have 7 + 1 + 5*input.length() + 1 + 1 primitive operations
        recursiveCount = recursiveCount + (10+(5*input.length()));
        //If the reverse string is equal to the input string, then the input is a palindrome
        if(reverse.equals(input))
        {
            recursiveCount++;
            //input is a palindrome
            return true;
        }
        else
        {
            recursiveCount++;
            //input is not a palindrome
            return false;
        }
    }

    public String decimalToBinary(String decimal)
    {
        //Convert the decimal String into an int
        //Then convert the int to a binary String
        //Return the binary String
        return Integer.toBinaryString(Integer.parseInt(decimal));
    }
}
```

Testing

Testing that each method correctly identifies palindromes

Method 1: isPalindromeStringEquals(String input)

Input = 0

Expected result: Is a palindrome

Actual result: `0: is a palindrome`

Input = 11

Expected result: Is a palindrome

Actual result: `11: is a palindrome`

Input = 101

Expected result: Is a palindrome

Actual result: `101: is a palindrome`

Input = 12

Expected result: Is not a palindrome

Actual result: `12 is not a palindrome`

Input = 12366466321

Expected result: Is a palindrome

Actual result: `12366466321: is a palindrome`

Method 2: isPalindromeCharacterByCharacter(String input)

Input = 0

Expected result: Is a palindrome

Actual result: `0: is a palindrome`

Input = 11

Expected result: Is a palindrome

Actual result: `11: is a palindrome`

Input = 101

Expected result: Is a palindrome

Actual result: `101: is a palindrome`

Input = 12

Expected result: Is not a palindrome

Actual result: `12 is not a palindrome`

Input = 12366466321

Expected result: Is a palindrome

Actual result: `12366466321: is a palindrome`

Method 3: isPalindromeStackQueue (String input)

Input = 0

Expected result: Is a palindrome

Actual result: `0: is a palindrome`

Input = 11

Expected result: Is a palindrome

Actual result: `11: is a palindrome`

Input = 101

Expected result: Is a palindrome

Actual result: `101: is a palindrome`

Input = 12

Expected result: Is not a palindrome

Actual result: `12 is not a palindrome`

Input = 12366466321

Expected result: Is a palindrome

Actual result: `12366466321: is a palindrome`

Method 4: isPalindromeRecursionReverse (String input)

Input = 0

Expected result: Is a palindrome

Actual result: `0: is a palindrome`

Input = 11

Expected result: Is a palindrome

Actual result: `11: is a palindrome`

Input = 101

Expected result: Is a palindrome

Actual result: `101: is a palindrome`

Input = 12

Expected result: Is not a palindrome

Actual result: `12 is not a palindrome`

Input = 12366466321

Expected result: Is a palindrome

Actual result: `12366466321: is a palindrome`

Utility method:

public String decimalToBinary(String decimal)

Input = decimal = “1000000”

Expected result: 1 million in binary

Using an online converter, 1 million in binary is:

11110100001001000000

Actual result:
11110100001001000000

```
Decimal to binary String test
Decimal: 1000000
Binary: 11110100001001000000
End of decimal to binary String test
```

Input = decimal = “0”

Expected result:
0

Actual result:
0

```
Decimal to binary String test
Decimal: 0
Binary: 0
End of decimal to binary String test
```

```
Decimal to binary String test
================================================
Decimal: 21
Binary: 10101
End of decimal to binary String test
================================================
```

Tests successful

Test the numbers 0-1000000 for palindromes

```
Initiating palindrome testing...

Run 1
==================================================
CSV data, paste into excel

0,0,0,0,0
50000,11233560,1887655,25886016,11606916
100000,23578200,3800462,54582291,24436020
150000,36767480,5662847,85188951,38194228
200000,50267480,7494813,116588368,52294228
250000,63767480,9326797,147988022,66394228
300000,77646040,11196630,180375865,80910644
350000,91646040,13078595,213080625,95560644
400000,105646040,14960573,245785996,110210644
450000,119646040,16842538,278490756,124860644
500000,133646040,18724523,311196637,139510644
550000,147903160,20581081,344562761,154443476
600000,162403160,22413580,378553024,169643476
650000,176903160,24246085,412543376,184843476
700000,191403160,26078613,446533651,200043476
750000,205903160,27911119,480524442,215243476
800000,220403160,29743635,514514521,230443476
850000,234903160,31576134,548504784,245643476
900000,249403160,33408651,582495332,260843476
950000,263903160,35241173,616485512,276043476
1000000,278403160,37073697,650476534,291243476
```

```
Results for run 1
---------------------------------------
Time taken for 0-1000000 (decimal only)
---------------------------------------
String Equals:          285ms
Character by Character: 43ms
Stack Queue:            324ms
Recursion Reverse:      710ms
---------------------------------------
Time taken for 0-1000000 (binary only)
---------------------------------------
String Equals:          472ms
Character by Character: 34ms
Stack Queue:            677ms
Recursion Reverse:      1845ms
---------------------------------------
Time taken for 0-1000000 (total of decimal and binary)
---------------------------------------
String Equals:          757ms
Character by Character: 77ms
Stack Queue:            1001ms
Recursion Reverse:      2555ms
```

```
---------------------------------------
Primitive operations for 0-1000000 (total of decimal and binary)
---------------------------------------
String Equals:          278403460 primitive operations
Character by Character: 37073728 primitive operations
Stack Queue:            650477110 primitive operations
Recursion Reverse:      291243791 primitive operations
---------------------------------------
Instances both bases palindromic for 0-1000000
---------------------------------------
Palindromic in both bases in: 20 instances
---------------------------------------
End of run 1
===============================================
```

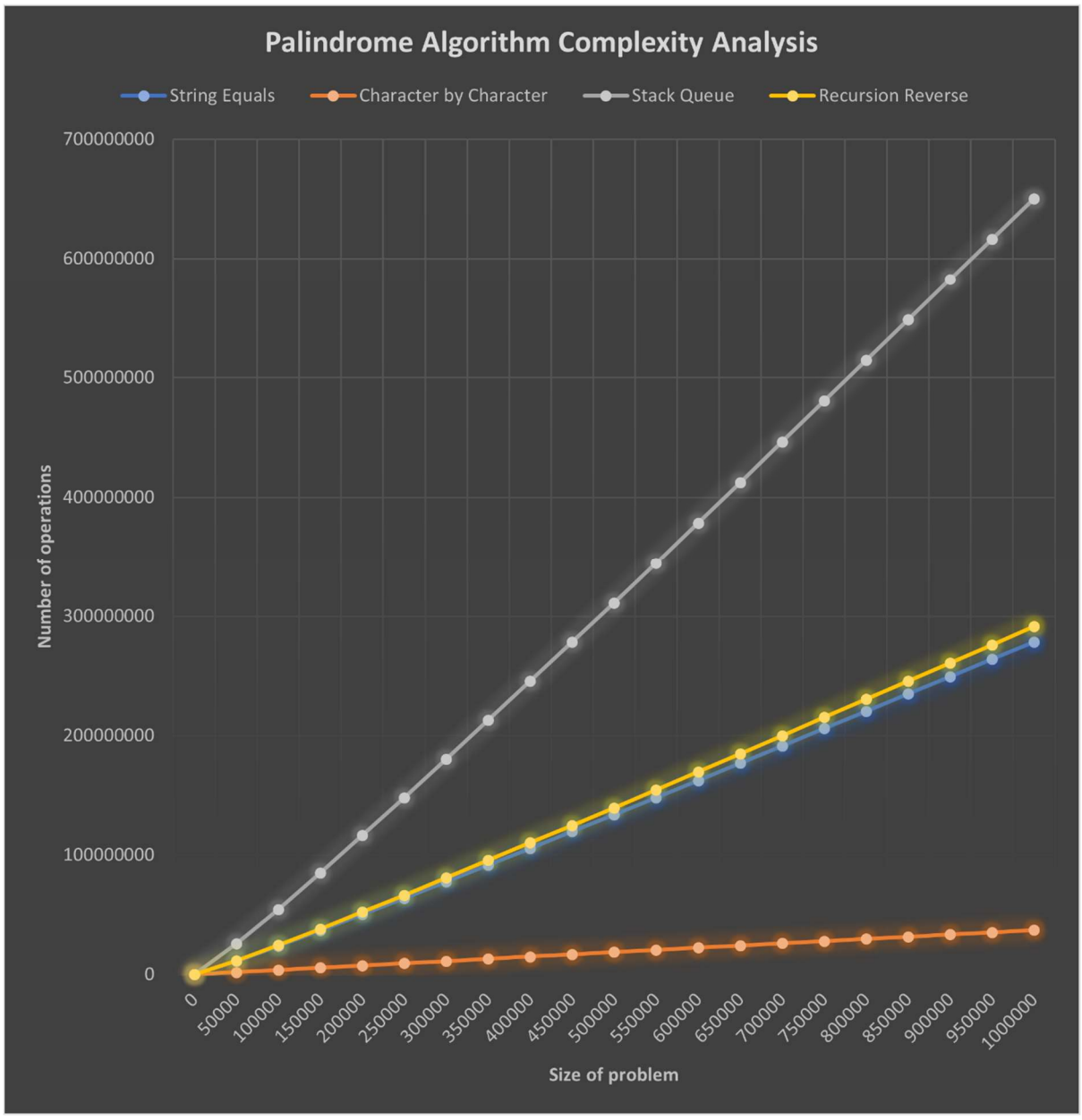
```
Run 2
================================================
CSV data, paste into excel

0,0,0,0,0
50000,11233560,1887655,25886016,11606916
100000,23578200,3800462,54582291,24436020
150000,36767480,5662847,85188951,38194228
200000,50267480,7494813,116588368,52294228
250000,63767480,9326797,147988022,66394228
300000,77646040,11196630,180375865,80910644
350000,91646040,13078595,213080625,95560644
400000,105646040,14960573,245785996,110210644
450000,119646040,16842538,278490756,124860644
500000,133646040,18724523,311196637,139510644
550000,147903160,20581081,344562761,154443476
600000,162403160,22413580,378553024,169643476
650000,176903160,24246085,412543376,184843476
700000,191403160,26078613,446533651,200043476
750000,205903160,27911119,480524442,215243476
800000,220403160,29743635,514514521,230443476
850000,234903160,31576134,548504784,245643476
900000,249403160,33408651,582495332,260843476
950000,263903160,35241173,616485512,276043476
1000000,278403160,37073697,650476534,291243476

Results for run 2
----------------------------------------
Time taken for 0-1000000 (decimal only)
----------------------------------------
String Equals:          248ms
Character by Character: 37ms
Stack Queue:            347ms
Recursion Reverse:      570ms
----------------------------------------
Time taken for 0-1000000 (binary only)
----------------------------------------
String Equals:          626ms
Character by Character: 35ms
Stack Queue:            770ms
Recursion Reverse:      2448ms
----------------------------------------
Time taken for 0-1000000 (total of decimal and binary)
----------------------------------------
String Equals:          874ms
Character by Character: 72ms
Stack Queue:            1117ms
Recursion Reverse:      3018ms
```

```
----------------------------------------
Primitive operations for 0-1000000 (total of decimal and binary)
----------------------------------------
String Equals:          278403460 primitive operations
Character by Character: 37073728 primitive operations
Stack Queue:            650477110 primitive operations
Recursion Reverse:      291243791 primitive operations
----------------------------------------
Instances both bases palindromic for 0-1000000
----------------------------------------
Palindromic in both bases in: 20 instances
----------------------------------------
End of run 2
================================================
```

```
Run 3
================================================
CSV data, paste into excel

0,0,0,0,0
50000,11233560,1887655,25886016,11606916
100000,23578200,3800462,54582291,24436020
150000,36767480,5662847,85188951,38194228
200000,50267480,7494813,116588368,52294228
250000,63767480,9326797,147988022,66394228
300000,77646040,11196630,180375865,80910644
350000,91646040,13078595,213080625,95560644
400000,105646040,14960573,245785996,110210644
450000,119646040,16842538,278490756,124860644
500000,133646040,18724523,311196637,139510644
550000,147903160,20581081,344562761,154443476
600000,162403160,22413580,378553024,169643476
650000,176903160,24246085,412543376,184843476
700000,191403160,26078613,446533651,200043476
750000,205903160,27911119,480524442,215243476
800000,220403160,29743635,514514521,230443476
850000,234903160,31576134,548504784,245643476
900000,249403160,33408651,582495332,260843476
950000,263903160,35241173,616485512,276043476
1000000,278403160,37073697,650476534,291243476
```

```
Results for run 3
---------------------------------------
Time taken for 0-1000000 (decimal only)
---------------------------------------
String Equals:          193ms
Character by Character: 19ms
Stack Queue:            221ms
Recursion Reverse:      512ms
---------------------------------------
Time taken for 0-1000000 (binary only)
---------------------------------------
String Equals:          497ms
Character by Character: 57ms
Stack Queue:            706ms
Recursion Reverse:      1478ms
---------------------------------------
Time taken for 0-1000000 (total of decimal and binary)
---------------------------------------
String Equals:          690ms
Character by Character: 76ms
Stack Queue:            927ms
Recursion Reverse:      1990ms
---------------------------------------
Primitive operations for 0-1000000 (total of decimal and binary)
---------------------------------------
String Equals:          278403460 primitive operations
Character by Character: 37073728 primitive operations
Stack Queue:            650477110 primitive operations
Recursion Reverse:      291243791 primitive operations
---------------------------------------
Instances both bases palindromic for 0-1000000
---------------------------------------
Palindromic in both bases in: 20 instances
---------------------------------------
End of run 3
===============================================

All runs complete

Process finished with exit code 0
```

Complexity analysis



Analysis

Every algorithm seems to have a linear time complexity because the number of operations seems to increase linearly and proportional to the size of the problem.

The **Stack Queue** method makes the most primitive operations. This explains why it has the second longest time to complete.

The **Recursion Reverse** method has the longest time to complete but does not use the most primitive operations. This could be due to the fact that, in the primitive operation count, I have not included the count of the primitive operations that Java is making to manage functions in its function stack. If these were included too, the recursion reverse method may have been the steepest gradient on the graph. This method was expected to be the slowest because recursion is known for being an elegant to write yet inefficient solution.

The **String Equals** method is the 2nd fastest and this corresponds to the results showing that it is the second fastest.

The graph for the **Character by Characte**r method shows that it is the most efficient of these 4 algorithms. It makes the least amount of primitive operations compared to the other 3 methods. The time taken results show that is also the quickest method, consistently finishing with the lowest time taken.