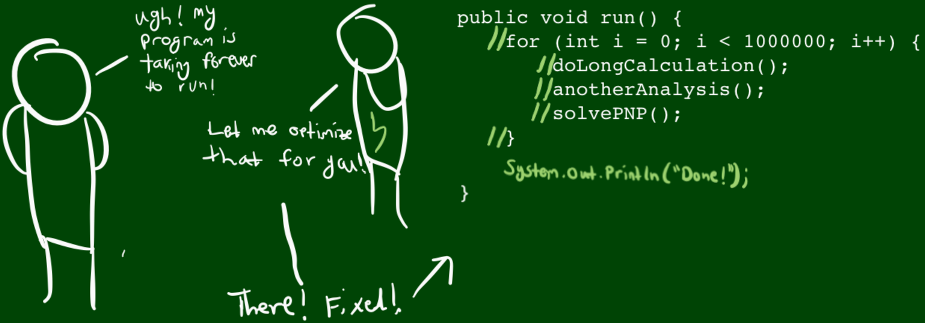
CSE 143

Computer Programming II

Efficiency



```
public void run() {
   //for (int i = 0; i < 1000000; i++) {
       //doLongCalculation();
       //anotherAnalysis();
       //solvePNP();
   //}
     System.out.Println("Done!");
}
```

ugh! my program is taking forever to run!
Let me optimize that for you!
There! Fixed!

Efficiency

What does it mean to have an “efficient program”?

```java
System.out.println("hello");
```

vs.

```java
System.out.print("h");
System.out.print("e");
System.out.print("l");
System.out.print("l");
System.out.println("o");
```

OUTPUT

```
>> left average run time is 1000 ns.
>> right average run time is 5000 ns.
```

We’re measuring in NANOSECONDS!

Both of these run **very very** quickly. The first is definitely better style, but it’s not “more efficient.”

Comparing Programs: Timing

hasDuplicate

Given a **sorted int array**, determine if the array has a duplicate.

```java
public boolean hasDuplicate1(int[] array) {
   for (int i=0; i < array.length; i++) {
      for (int j=0; j < array.length; j++) {
         if (i != j && array[i] == array[j]) {
            return true;
         }
      }
   }
   return false;
}

public boolean hasDuplicate2(int[] array) {
   for (int i=0; i < array.length − 1; i++) {
      if (array[i] == array[i+1]) {
         return true;
      }
   }
   return false;
}
```

OUTPUT

```
>> hasDuplicate1 average run time is 5254712 ns.
>> hasDuplicate2 average run time is 2384 ns.
```

Comparing Programs: # Of Steps

Timing programs is prone to error:

- We can't compare between computers
- We get noise (what if the computer is busy?)

Let's **count** the number of steps instead:

```java
public int stepsHasDuplicate1(int[] array) {
   int steps = 0;
   for (int i=0; i < array.length; i++) {
      for (int j=0; j < array.length; j++) {
         steps++; // The if statement is a step
         if (i != j && array[i] == array[j]) {
            return steps;
         }
      }
   }
   return steps;
}
```

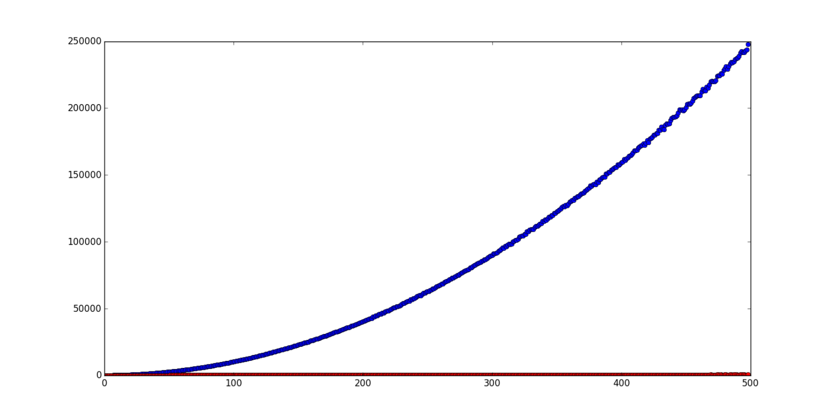
OUTPUT

```
>> hasDuplicate1 average number of steps is 9758172 steps.
>> hasDuplicate2 average number of steps is 170 steps.
```

Comparing Programs: Plotting

This **still** isn't good enough! We're only trying **a single** array!

Instead, let's try running on arrays of size 1, 2, 3, . . . , 1000000, and plot:



Comparing Programs: Analytically

Runtime Efficiency

We've made the following observations:

- All "simple" statements (println("hello"), 3 + 7, etc.) take **one** step to run.
- We should look at the "number of steps" a program takes to run.
- We should compare the **growth** of the runtime (not just one input).

```
statement1;
statement2;
statement3;

for (int i = 0; i < N; i++) {
   statement4;
}


for (int i = 0; i < N; i++) {
   statement5;
   statement6;
   statement7;
   statement8;
}
```

3

N

$4N$

$5N + 3$

Big-Oh

We measure **algorithmic complexity** by looking at the **growth rate** of the steps vs. the size of the input.

The algorithm on the previous slide ran in $5N+3$ steps. As N gets very large, the “5” and the “3” become irrelevant.

We say that algorithm is $\mathcal{O}(N)$ (“Big-Oh-of-N”) which means the number of steps it takes is **linear** in the input.

Some Common Complexities

$\mathcal{O}(1)$	Constant	The number of steps doesn’t depend on n
$\mathcal{O}(n)$	Linear	If you double n, the number of steps **doubles**
$\mathcal{O}(n^2)$	Quadratic	If you double n, the number of steps **quadruples**
$\mathcal{O}(2^n)$	Exponential	The number of steps gets infeasible at $n < 100$

More Examples

```
statement1;
statement2;    } 3
statement3;

for (int i = 0; i < N; i++) {
   statement4;
   for (int j=0; j < N/2; j++) {
      statement5;                  } N/2   } N + N(N/2)
   }                                                        } 0.5N^2 + 5N + 3
}


for (int i = 0; i < N; i++) {
   statement6;
   statement7;                     } 4N
   statement8;
   statement9;
}
```

So, the entire thing is $\mathcal{O}(N^2)$, because the quadratic term overtakes all the others.

`ArrayList` Efficiency

`add(`**val**`)`	$\mathcal{O}(1)$
`add(`**idx**, **val**`)`	$\mathcal{O}(n)$
`get(`**idx**`)`	$\mathcal{O}(1)$
`set(`**idx**, **val**`)`	$\mathcal{O}(1)$
`remove(`**idx**`)`	$\mathcal{O}(n)$
`size()`	$\mathcal{O}(1)$

`ArrayList` Example

What are the time complexities of these functions?

```
public static void numbers1(int max) {
   ArrayList<Integer> list = new ArrayList<Integer>(); //𝒪(1)
   for (int i = 1; i < max; i++) {
      list.add(i); //𝒪(1)
   }
}
```

$\mathcal{O}(n)$

$\mathcal{O}(n)$

vs.

```
public static void numbers2(int max) {
   ArrayList<Integer> list = new ArrayList<Integer>(); //𝒪(1)
   for (int i = 1; i < max; i++) {
      list.add(i); //𝒪(1)
      list.add(i); //𝒪(1)
   }
}
```

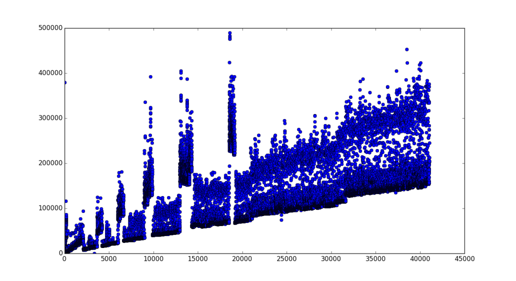
$\mathcal{O}(1)$

$\mathcal{O}(n)$

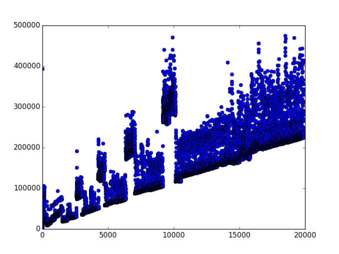
$\mathcal{O}(n)$

Investigating Our Answer With Pictures

numbers1



numbers2



Find the Runtime

```java
public boolean is10(int number) {
   return number == 10;
}
```

$\mathcal{O}(1)$

```java
public boolean two10s(int num1, int num2, int num3) {
   return (is10(num1) && is10(num2) && !is10(num3)) ||
          (is10(num1) && !is10(num2) && is10(num3)) ||
          (!is10(num1) && is10(num2) && is10(num3));
}
```

$\mathcal{O}(1)$

```java
public void loops(int N) {
   for (int i = 0; i < N; i++) {
      for (int j = 0; j < N; j++) {
         System.out.println(i + " " + j);
      }
   }


   for (int i = 0; i < N; i++) {
      System.out.println(N – i);
   }
}
```

$\mathcal{O}(n^2)$

$\mathcal{O}(n^2)$

$\mathcal{O}(n)$

It’s the WORST CASE!

```java
public static int has5(int[] array) {
   for (int i = 0; i < array.length; i++) {
      System.out.println(array[i]); //𝒪(1)
      if (array[i] == 5) { //𝒪(1)
         return true;      //𝒪(1)
      }
   }
   return false;           //𝒪(1)
}
```

$\mathcal{O}(1)$

$\mathcal{O}(n)$

$\mathcal{O}(n)$

Sometimes, these will finish in fewer than `array.length` steps, but **in the worse case**, we have to go through the whole array. This makes both of them $\mathcal{O}(n)$.