Big-O, Stacks, and Queues

Objectives

1. Undstand the utility of big-O notation
2. Compare ArrayList and LinkedList on the basis of big-O notation
3. Understand the distinction between stacks and queues.
4. Use the Queue interface and Stack and their common methods in Java.
5. Use a stack to build an RPN calculator.
6. Use a queue to simulate round robin process scheduling.

Algorithmic Complexity

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   - **Space Complexity:** The amount of memory we can expect an operation to take, in the worst case.

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3. Today we will focus on time complexity.

Algorithmic Complexity

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4. Denoted as $O(\text{input space})$ to represent the upper bound (i.e., the worst case).

Analyzing Algorithms

```
public void printList(Integer item){
    System.out.println(item);
}
```

```
public void printList(List<Integer> lst){
    for(int i = 0; i < lst.size(); i++){
        System.out.println(lst.get(i));
    }
}
```

```
public void multiplyAndPrint(Integer item1, Integer item2){
    int result = item1 * item2;
    System.out.println(result);
}
```

What is the maximum number of operations each method will perform? What is the minimum?

An example of constant time

```java
public void multiplyAndPrint(Integer item1, Integer item2){
    int result = item1 * item2;
    System.out.println(result);
}
```

```java
public void pow(Integer item1, Integer item2){
    int result = item1 * item2;
    System.out.println(result);
}
```

```java
public void multiplyAndPrint(Integer item1, Integer item2){
    int result = item1 * item2;
    System.out.println(result);
}
```

All of the above are treated as $O(1)$ since they don't increase with input size.

Analyzing Algorithms

```java
public void printList(List<Integer> lst){
    for(int i = 0; i < lst.size(); i++){
        System.out.println(lst.get(i));
    }
}
```

```java
public void printList(List<Integer> lst){
    for(int i = 0; i < lst.size(); i++){
        for(int j = 0; j < lst.size(); j++){
            System.out.println(lst.get(i) * lst.get(j));
        }
    }
}
```

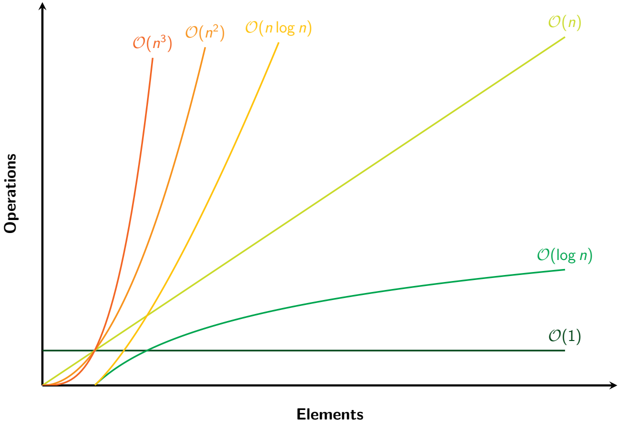
If one for loop (the first one) is $O(N)$, what is a nested for loop (the second one)?

Analyzing Algorithms

```java
public void printList(List<Integer> lst){
    for(int i = 0; i < lst.size(); i++){
        System.out.println(lst.get(i));
    }
    for(int i = 0; i < lst.size(); i++){
        System.out.println(lst.get(i));
    }
}
```

So is two for loops, unnested, $O(2N)$?.

Examples


$\mathcal{O}(n^3)$
$\mathcal{O}(n^2)$
$\mathcal{O}(n \log n)$
$\mathcal{O}(n)$
$\mathcal{O}(\log n)$
$\mathcal{O}(1)$
Operations
Elements

ArrayList vs LinkedList - Searching

```java
public void search(ListNode<E> head, E data){
    ListNode<E> tmp = head;
    while(tmp != null && !tmp.data.equals(data)){
        tmp = tmp.next;
    }
    return tmp;
}
```

1. **LinkedList:** O(N) since we have to traverse to find the item.
2. **ArrayList:** O(N) since we also have to traverse the item.

ArrayList vs LinkedList - Getting Item at Index

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2. What would the complexity be for getFront() or getEnd() be for a LinkedList? How would this depend on whether we are keeping track of the tail?

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    1. **LinkedList:** O(N) since we have to traverse to find the item.
    2. **ArrayList:** O(1) since we can index.
2. What would the complexity be for getFront() or getEnd() be for a LinkedList? How would this depend on whether we are keeping track of the tail?
    1. **LinkedList wo/ tail:** $O(1)$ to get head and $O(N)$ to get last node.
    2. **LinkedList w/ tail:** $O(1)$ for each.

ArrayList vs LinkedList - Insertion/Removal

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    3. So both are O(N).

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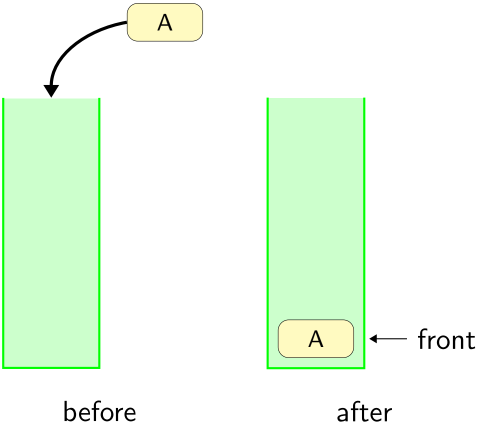
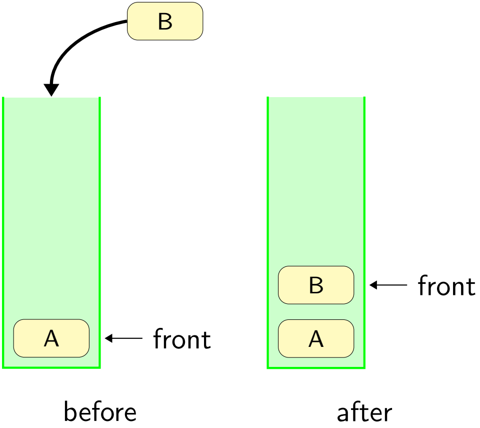
    3. So both are O(N).
3. Adding/removing to the end?
    1. **LinkedList (wo/tail):** O(N) since we have to search for the end.
    2. **LinkedList (w/tail):** O(1) for adding since we track the tail.
    3. **ArrayList:** Finding the position is O(1) and since it's at the end

Stacks

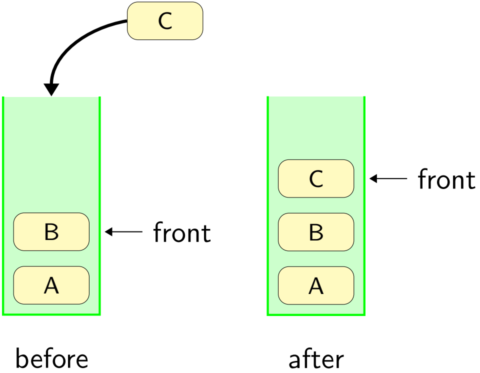
1. Last in, First out (LIFO) data structure.
2. Stack is a class Java
3. Uses the following operations:
    1. push to add to the top of the stack.
    2. pop to remove the element at the top of the stack.



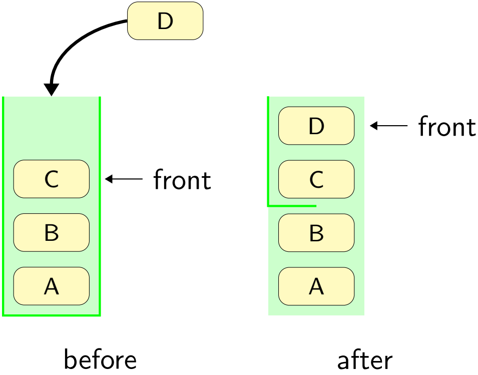
```
Stack<Integer> nums = new Stack<>();
nums.push("A")
```



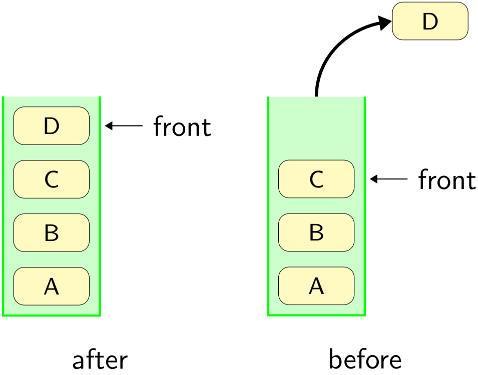
```
Stack<Integer> nums = new Stack<>();
nums.push("A")
nums.push("B")
```



```
Stack<Integer> nums = new Stack<>();
nums.push("A")
nums.push("B")
nums.push("C")
```



```
Stack<Integer> nums = new Stack<>();
nums.push("A")
nums.push("B")
nums.push("C")
nums.push("D")
```



```
Stack<Integer> nums = new Stack<>();
nums.push("A")
nums.push("B")
nums.push("C")
nums.push("D")
nums.pop()
```

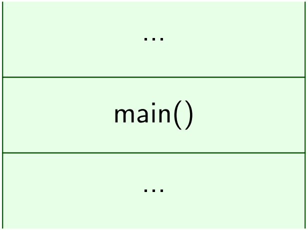
Q: Where is this used? A: Call Stacks

```java
public class PowerClass {

   public static int mult(int times, int val){
      int product = 0;
      for(int i = 0; i < times; i++){
         product += val;
      }
      return product;
   }

   public static int pow(int num, int raise){
      int total = 1;
      for(int i = 0; i < raise; i ++){
         total = mult(total, num);
      }
      return total;
   }

   public static void main(String[] args) {
      pow(2, 5);
   }
}
```


...

main()

...

Our program starts at main.

Q: Where is this used? A: Call Stacks

```java
public class PowerClass {

   public static int mult(int times, int val){
      int product = 0;
      for(int i = 0; i < times; i++){
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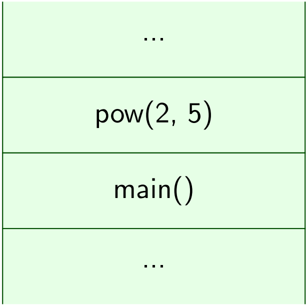
      }
      return total;
   }

   public static void main(String[] args) {
      pow(2, 5);
   }
}
```


...

pow(2, 5)

main()

...

Our program starts at the pow method is then called an placed on the call stack.

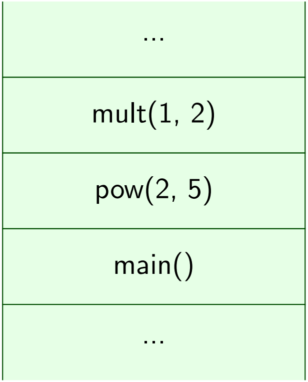
Q: Where is this used? A: Call Stacks

```
public class PowerClass {

   public static int mult(int times, int val){
      int product = 0;
      for(int i = 0; i < times; i++){
         product += val;
      }
      return product;
   }

   public static int pow(int num, int raise){
      int total = 1;
      for(int i = 0; i < raise; i ++){
         total = mult(total, num);
      }
      return total;
   }

   public static void main(String[] args) {
      pow(2, 5);
   }
}
```



...

mult(1, 2)

pow(2, 5)

main()

...

The pow method then calls the mutl method.

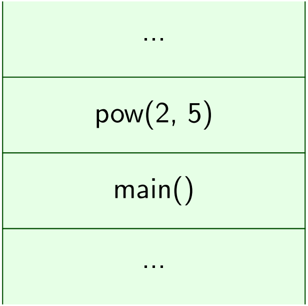
Q: Where is this used? A: Call Stacks

```
public class PowerClass {

   public static int mult(int times, int val){
      int product = 0;
      for(int i = 0; i < times; i++){
         product += val;
      }
      return product;
   }

   public static int pow(int num, int raise){
      int total = 1;
      for(int i = 0; i < raise; i ++){
         total = mult(total, num);
      }
      return total;
   }

   public static void main(String[] args) {
      pow(2, 5);
   }
}
```



...

pow(2, 5)

main()

...

Once the call to mult is completed it is “popped” off of the stack and we return to where we left off in pow.

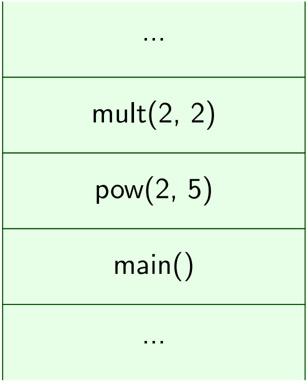
Q: Where is this used? A: Call Stacks

```
public class PowerClass {

   public static int mult(int times, int val){
      int product = 0;
      for(int i = 0; i < times; i++){
         product += val;
      }
      return product;
   }

   public static int pow(int num, int raise){
      int total = 1;
      for(int i = 0; i < raise; i ++){
         total = mult(total, num);
      }
      return total;
   }

   public static void main(String[] args) {
      pow(2, 5);
   }
}
```


...

mult(2, 2)

pow(2, 5)

main()

...

We then call the mult method again.

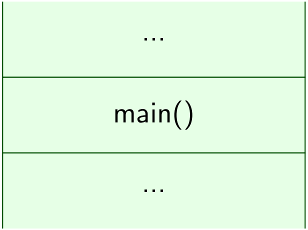
Q: Where is this used? A: Call Stacks

```
public class PowerClass {

  public static int mult(int times, int val){
    int product = 0;
    for(int i = 0; i < times; i++){
      product += val;
    }
    return product;
  }

  public static int pow(int num, int raise){
    int total = 1;
    for(int i = 0; i < raise; i ++){
      total = mult(total, num);
    }
    return total;
  }

  public static void main(String[] args) {
    pow(2, 5);
  }
}
```



We continue this until pow is complete and then pop it off the stack.

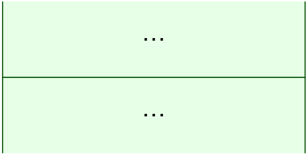
Q: Where is this used? A: Call Stacks

```
public class PowerClass {

   public static int mult(int times, int val){
      int product = 0;
      for(int i = 0; i < times; i++){
         product += val;
      }
      return product;
   }

   public static int pow(int num, int raise){
      int total = 1;
      for(int i = 0; i < raise; i ++){
         total = mult(total, num);
      }
      return total;
   }

   public static void main(String[] args) {
      pow(2, 5);
   }
}
```



main has finished so that is popped as well and the program terminates.

Worksheet: Stack Practice

Off to work on the worksheet to play with stacks.

RPN Calculator

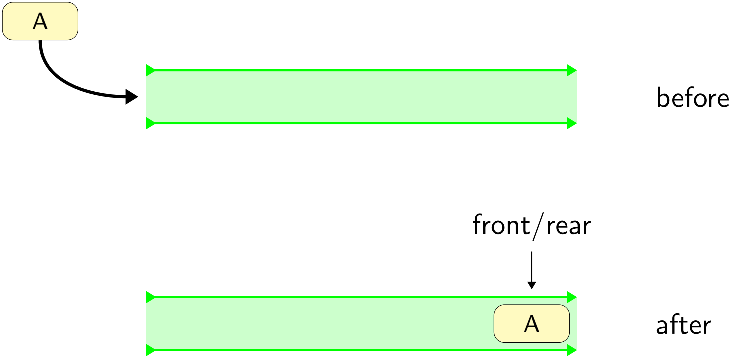
Look at each element in the list and, at each stage:

1. If an element is an operation (i.e., +/-):
    1. Pop two numbers from the stack
    2. Perform the operation
    3. Push the result onto the stack
2. Otherwise, it must be a string representation of a number so:
    1. Convert it to an ‘Integer‘
    2. Push it to the stack

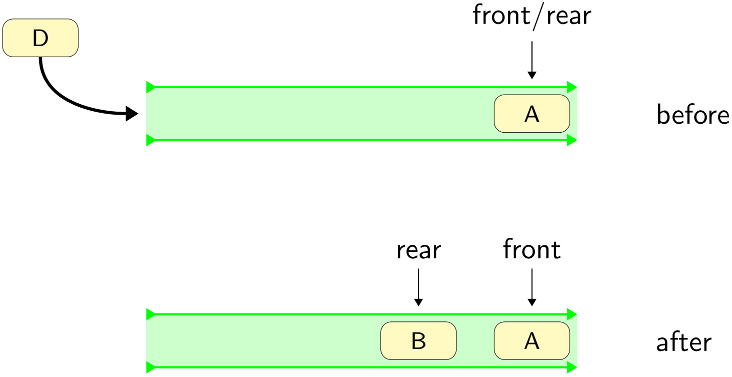
Worksheet: RPN Calculator

Off to work on the worksheet to implement the RPN calculator

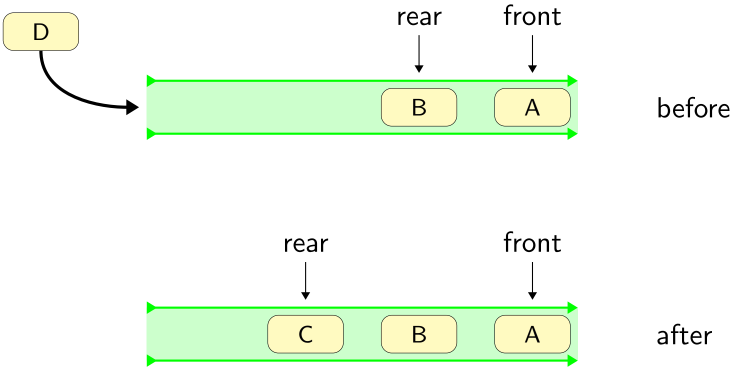
1. First in, First out (FIFO) data structure.
2. `Queue` is an interface in Java.
3. Uses the following operations:
    1. enqueue: to add to the end of a queue.
    2. dequeue: to remove the element at the front of the queue.



```
Queue<Integer> nums = new ArrayDequeue<>();
nums.offer("A")
```



```
Queue<Integer> nums = new ArrayDequeue<>();
nums.offer("A")
nums.offer("B")
```



D

rear

front

B

A

before

rear

front

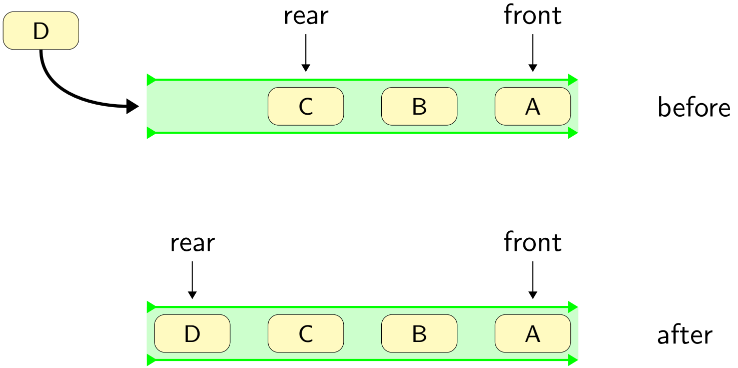
C

B

A

after

```
Queue<Integer> nums = new ArrayDequeue<>();
nums.offer("A")
nums.offer("B")
nums.offer("C")
```



```
Queue<Integer> nums = new ArrayDequeue<>();
nums.offer("A")
nums.offer("B")
nums.offer("C")
nums.offer("D")
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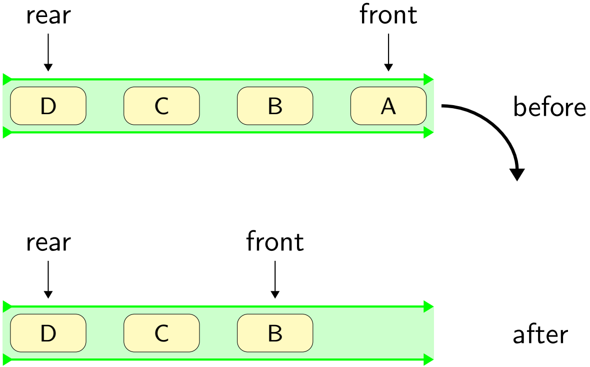

```
Queue<Integer> nums = new ArrayDequeue<>();
nums.offer("A")
nums.offer("B")
nums.offer("C")
nums.offer("D")
nums.poll()
```

Worksheet: Queue Practice

Off to work on the worksheet to play with queues.

Process Scheduling

1. Dequeue a process
2. Check if the allowed processing time (quanta) is less than the time remaining to serve that proccess:
3. If it is:
    1. reduce the proc's remaining time by that quanta
    2. increment the total process time by the quanta
    3. increment that proc's contex switch count
    4. enqueue the process
    5. Print a message indicating the name of the process and it's quanta
4. Otherwise:
    1. increment the total processing time by the time remaining for that process
    2. print a message indicating the event name, the total time the process spent in the queue, and the number of time's it was switched out of context.

Worksheet: Round Robin Scheduler

Off to work on the worksheet to implement a round robin simulator.

Application: Card Game