CSCI 132:
Basic Data Structures and Algorithms

Queues (Array Implementation)

Reese Pearsall

Spring 2024

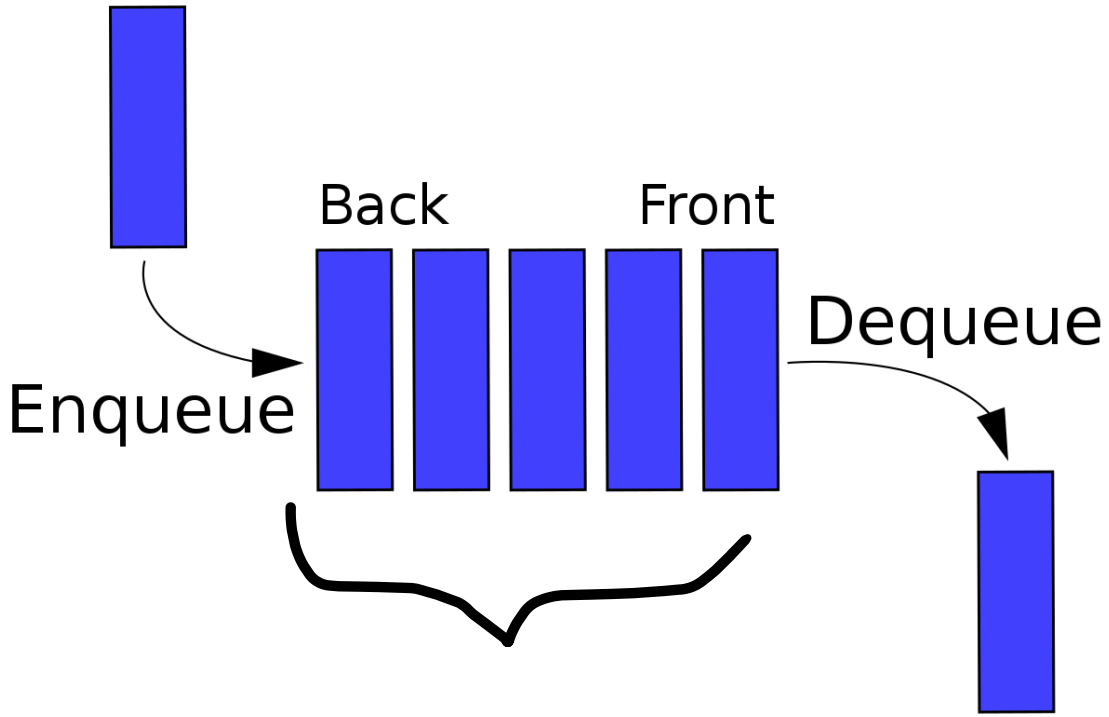
Announcements

Lab 9 due **tomorrow** 4/2
@ 11:59 PM (Queues)

No office hours tomorrow ☺

Program 3 due this Friday 4/5

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion

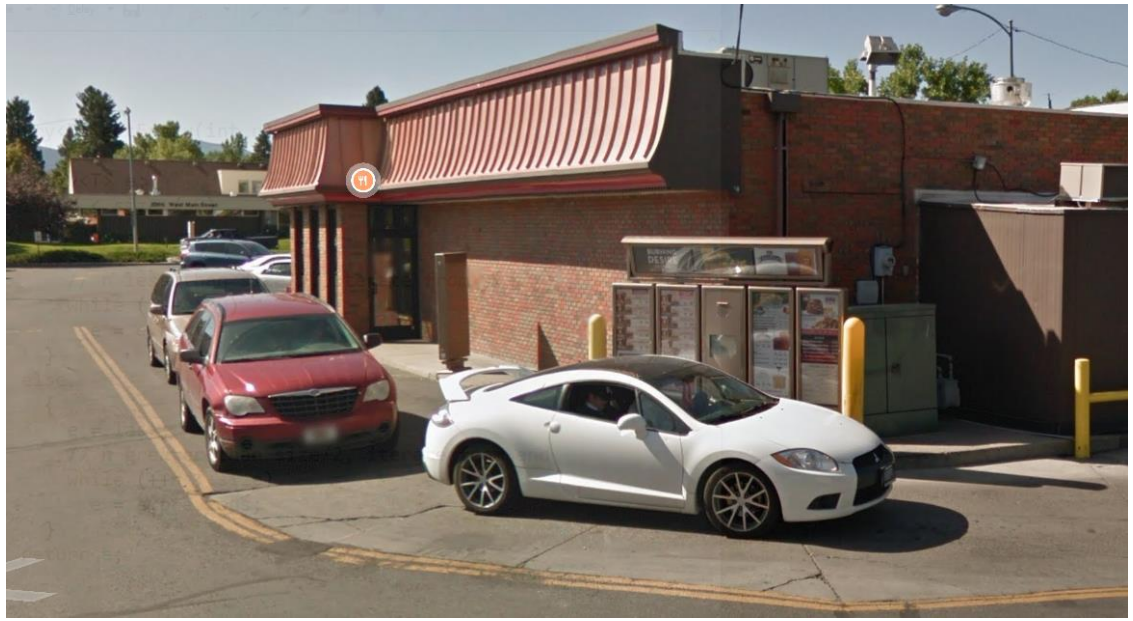


Once again, we need a data structure to hold the data of the queue

- Linked List
- Array

Elements get added to the **`Back`** of the Queue.

Elements get removed from the **`Front`** of the queue



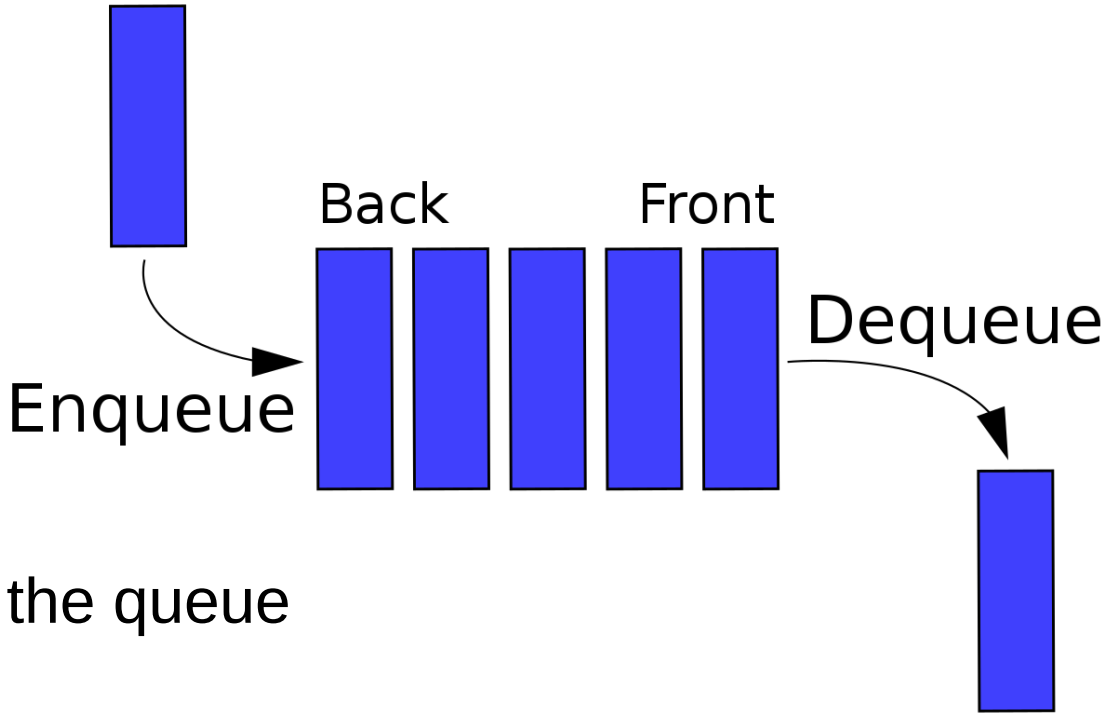
A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion

The Queue ADT has the following methods:

Enqueue- Add new element to the queue

Dequeue- Remove element from the queue

** Always remove the front-most element

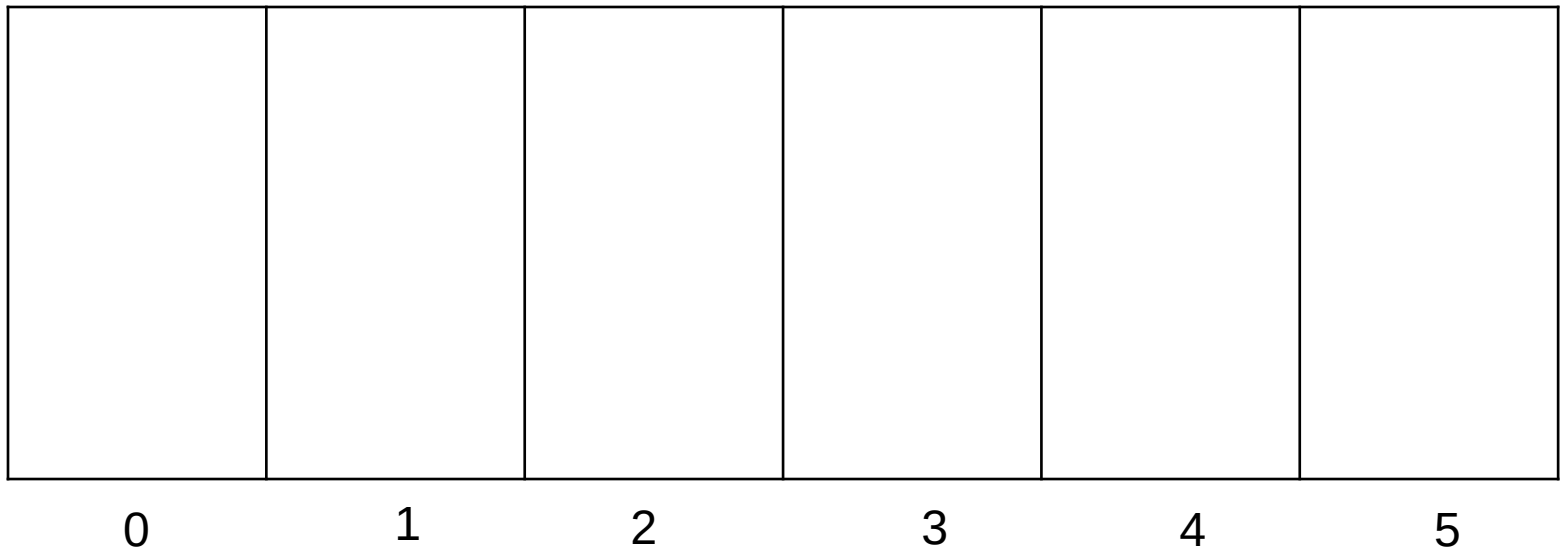


Peek()- Return the element that is at the front of the queue

IsEmpty() – Returns true if queue is empty, returns false is queue is not empty

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements



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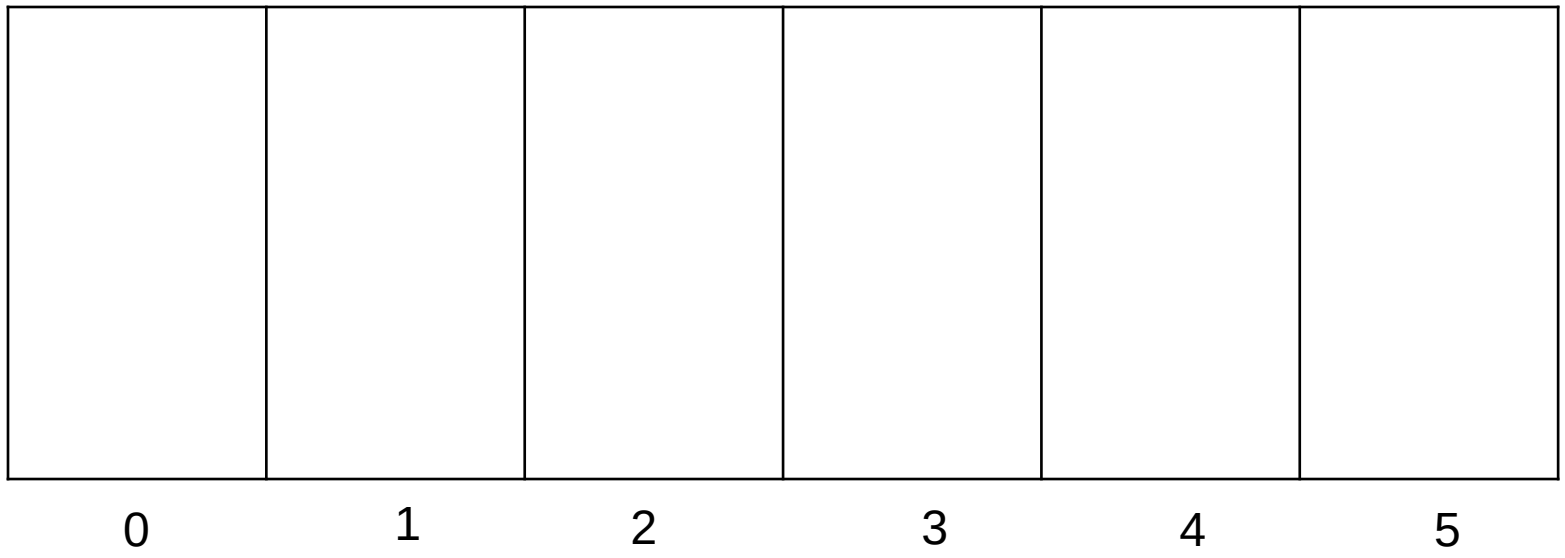

We need to keep track of a few things:

1. The index of the **front** of the queue
2. The index of the rear of the queue
3. The size of the queue
4. The capacity of the queue

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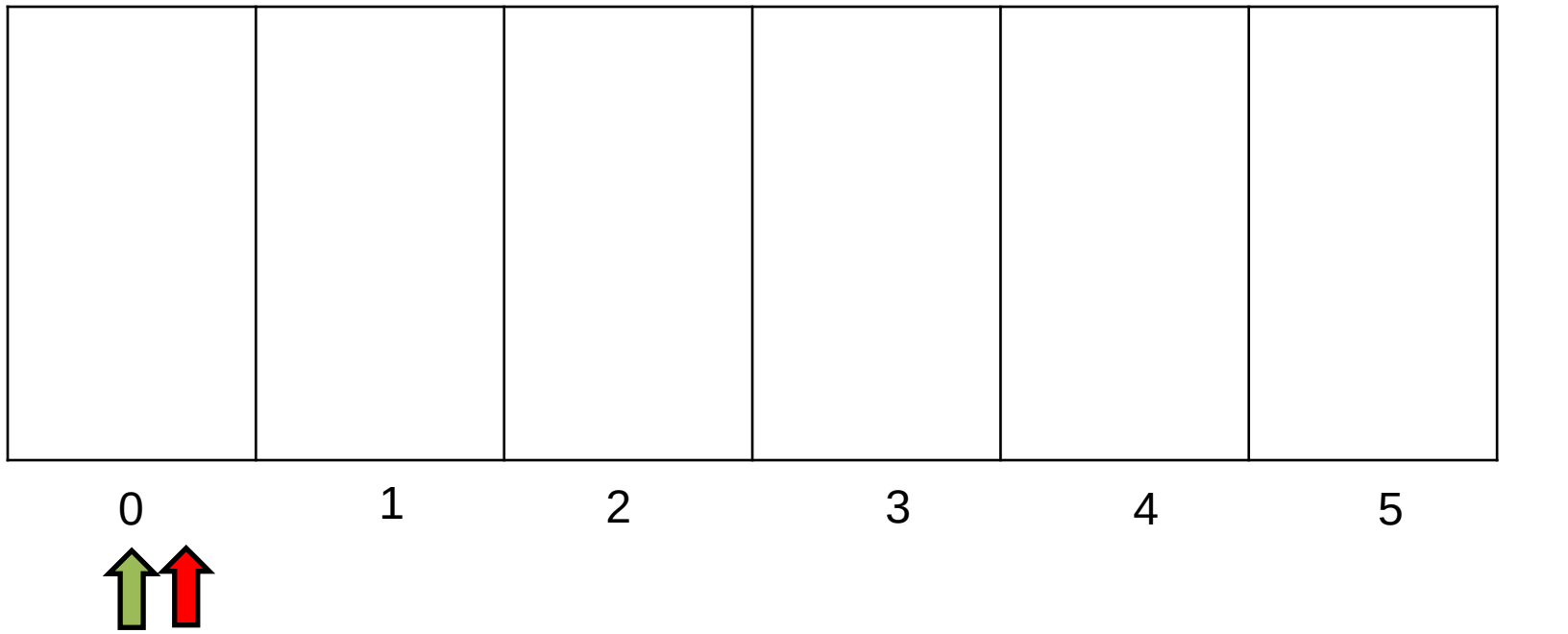


```
capacity = 6    front = 0
size = 0        rear = 0
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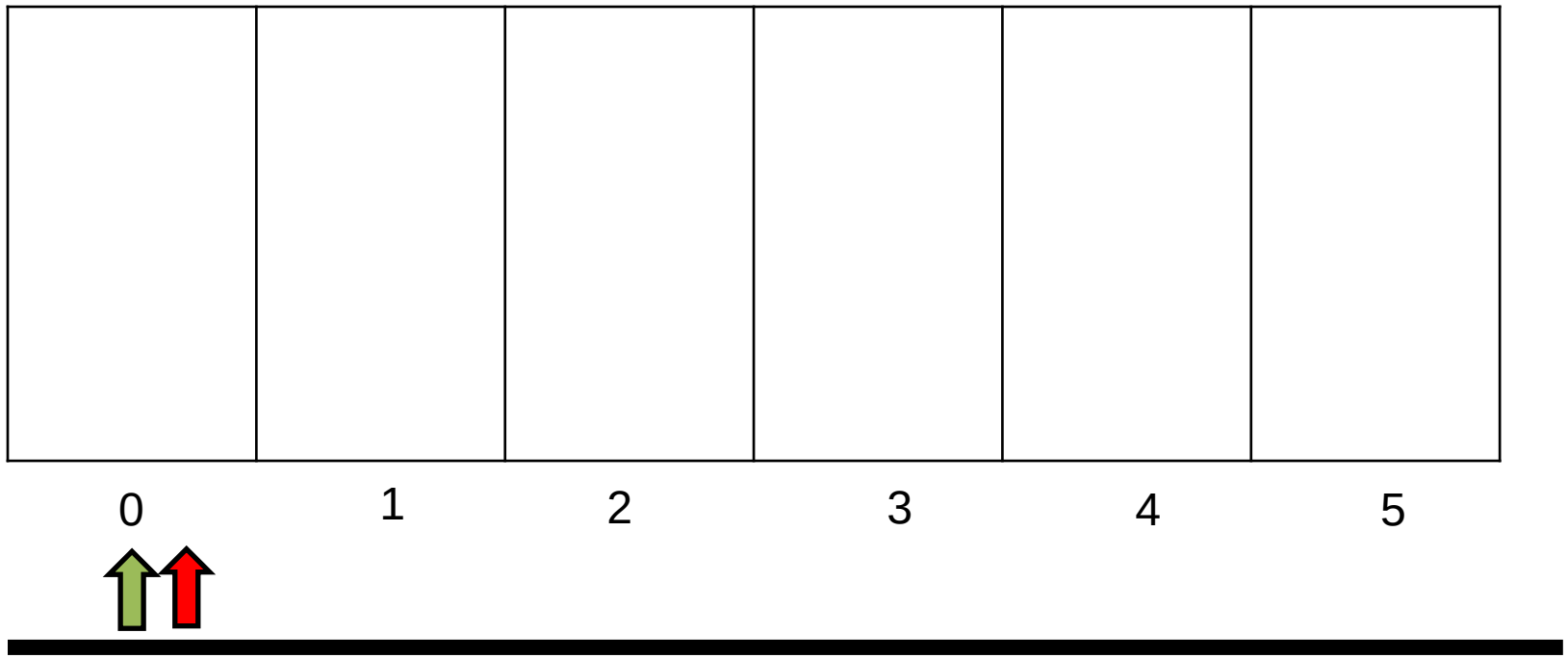


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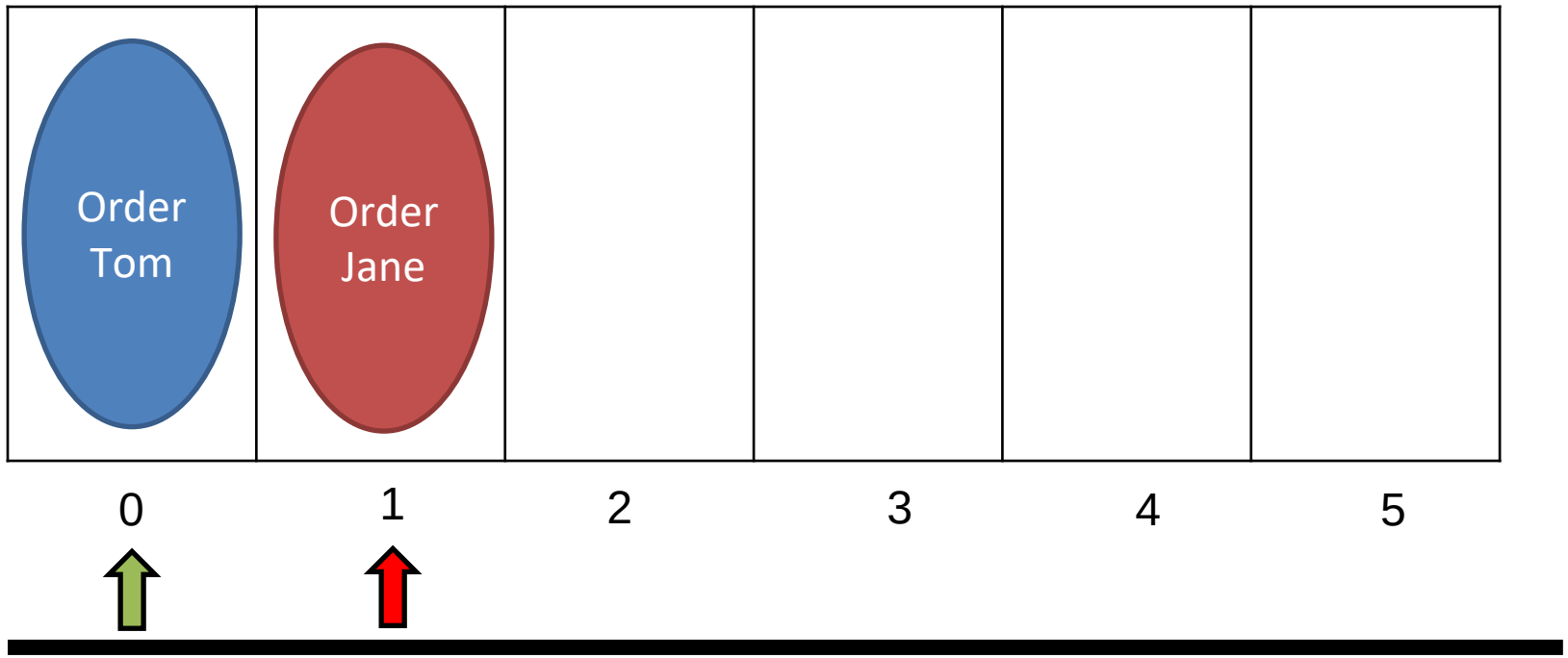


```
capacity = 6    front = 0
size = 2        rear = 1
```

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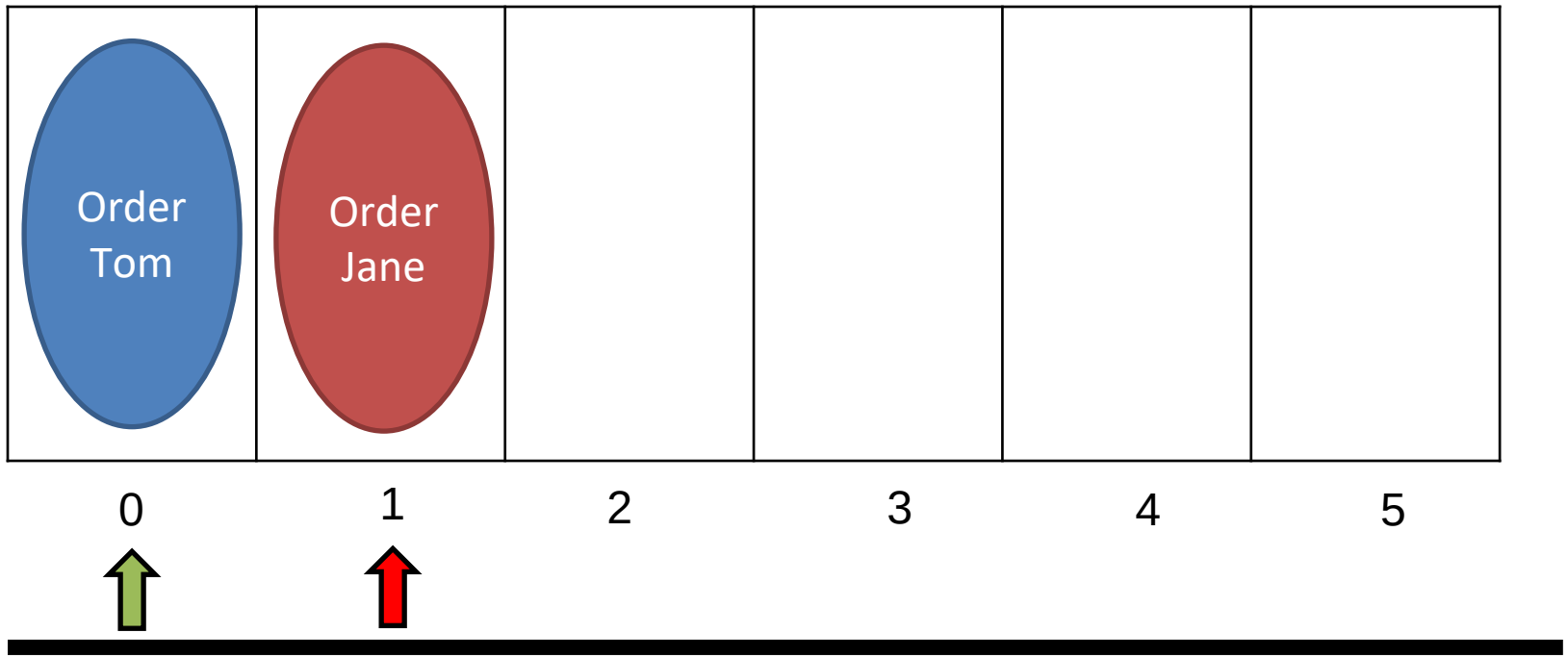

Enqueue?

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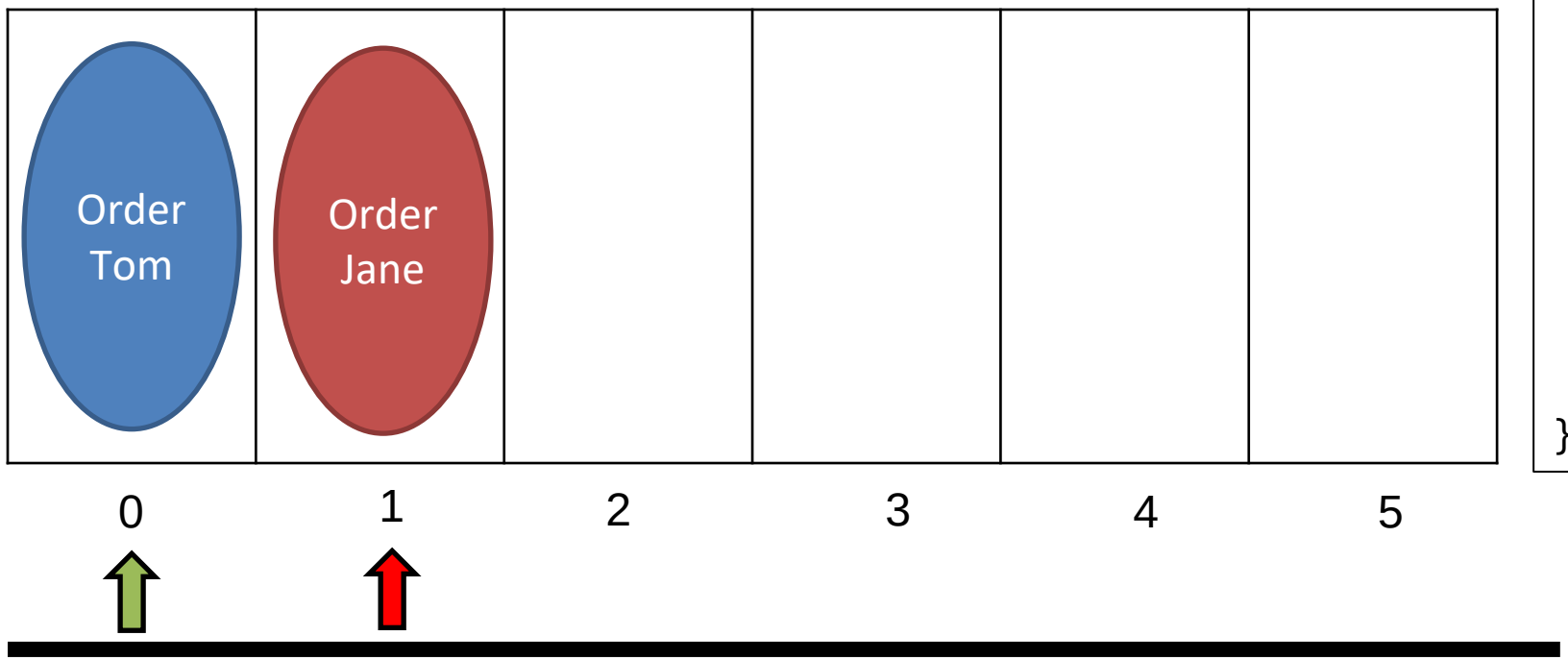


```
public void enqueue(Order newOrder) {
  if(rear == capacity) {
    System.out.println("full...");
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  }
  else {
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    this.data[rear] = newOrder;
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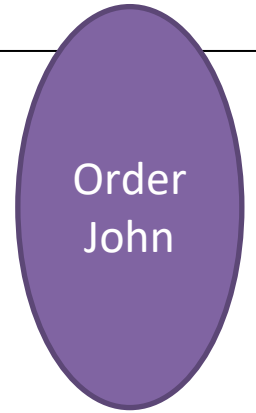
```

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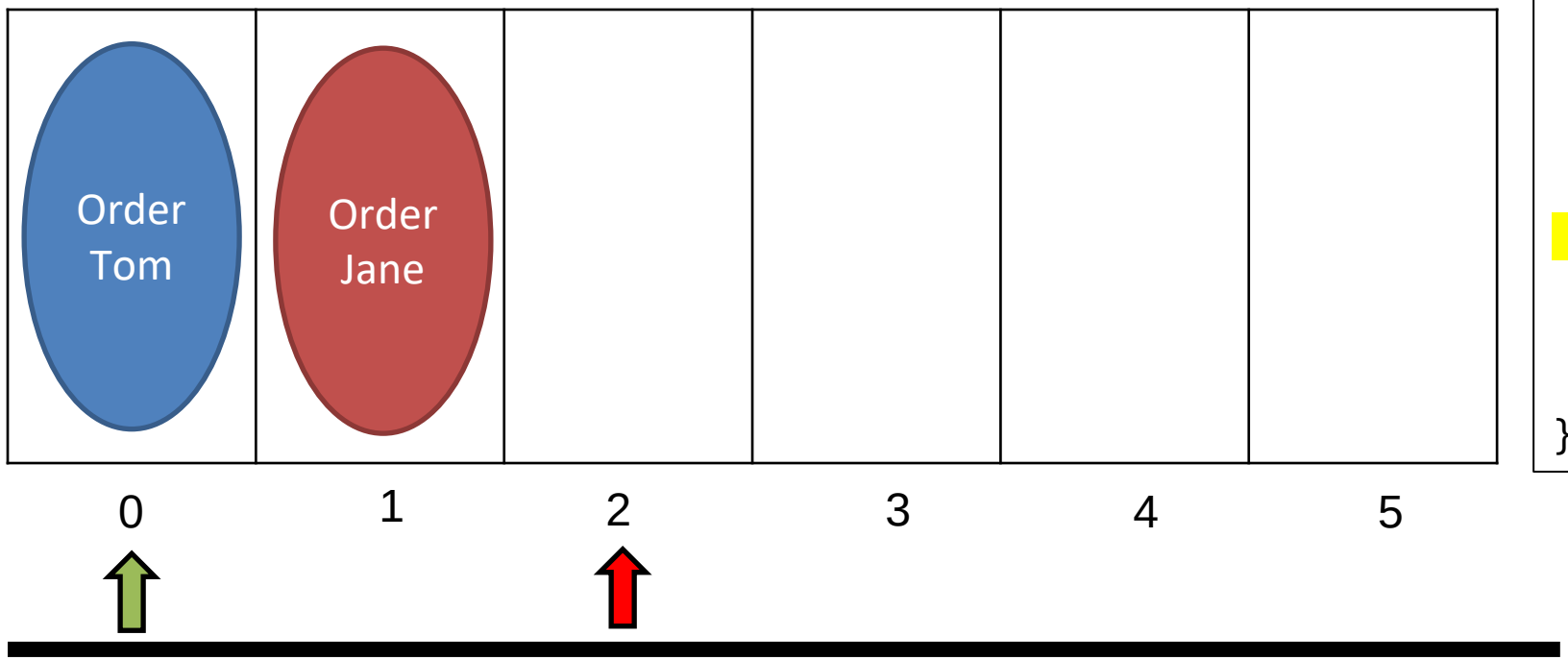


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```

Order
John

capacity = 6 front = 0

size = 2 rear = 2

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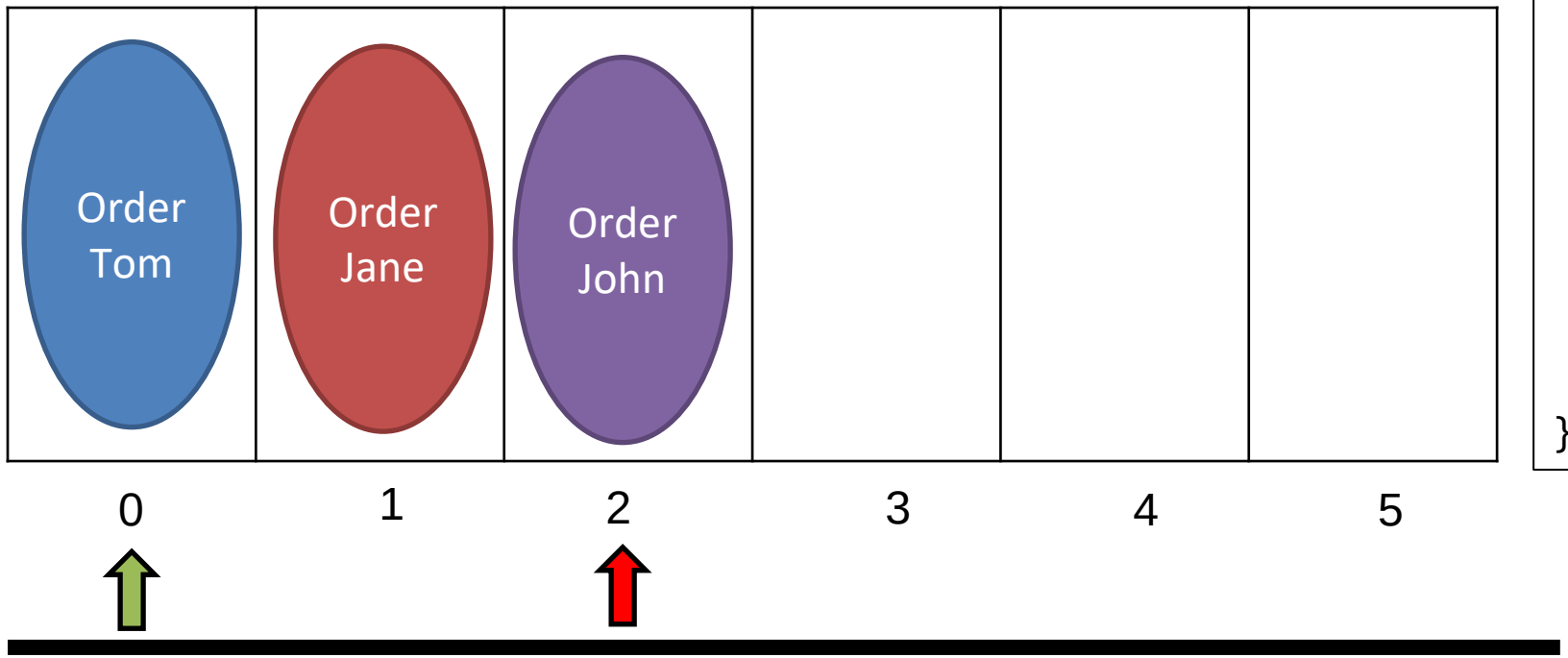


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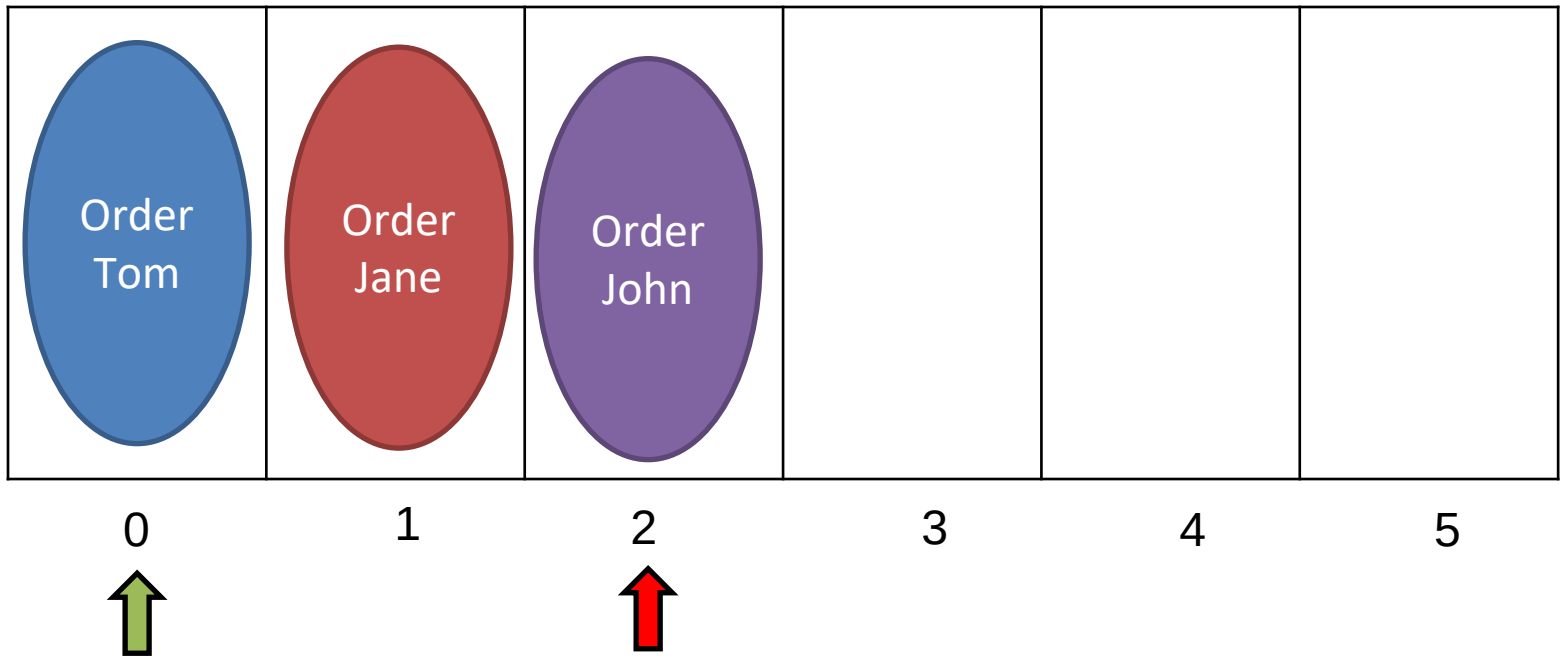


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`capacity = 6` `front = 0`

`size = 3` `rear = 2`

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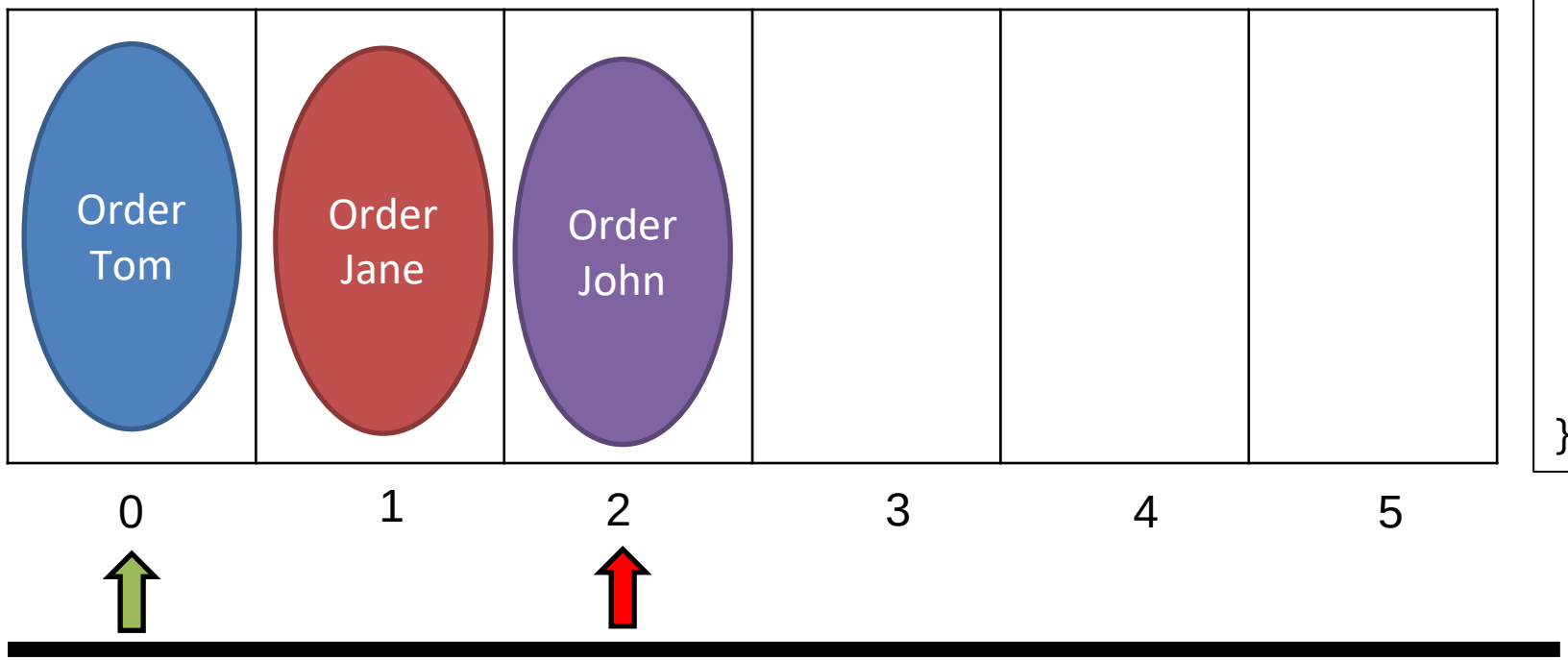


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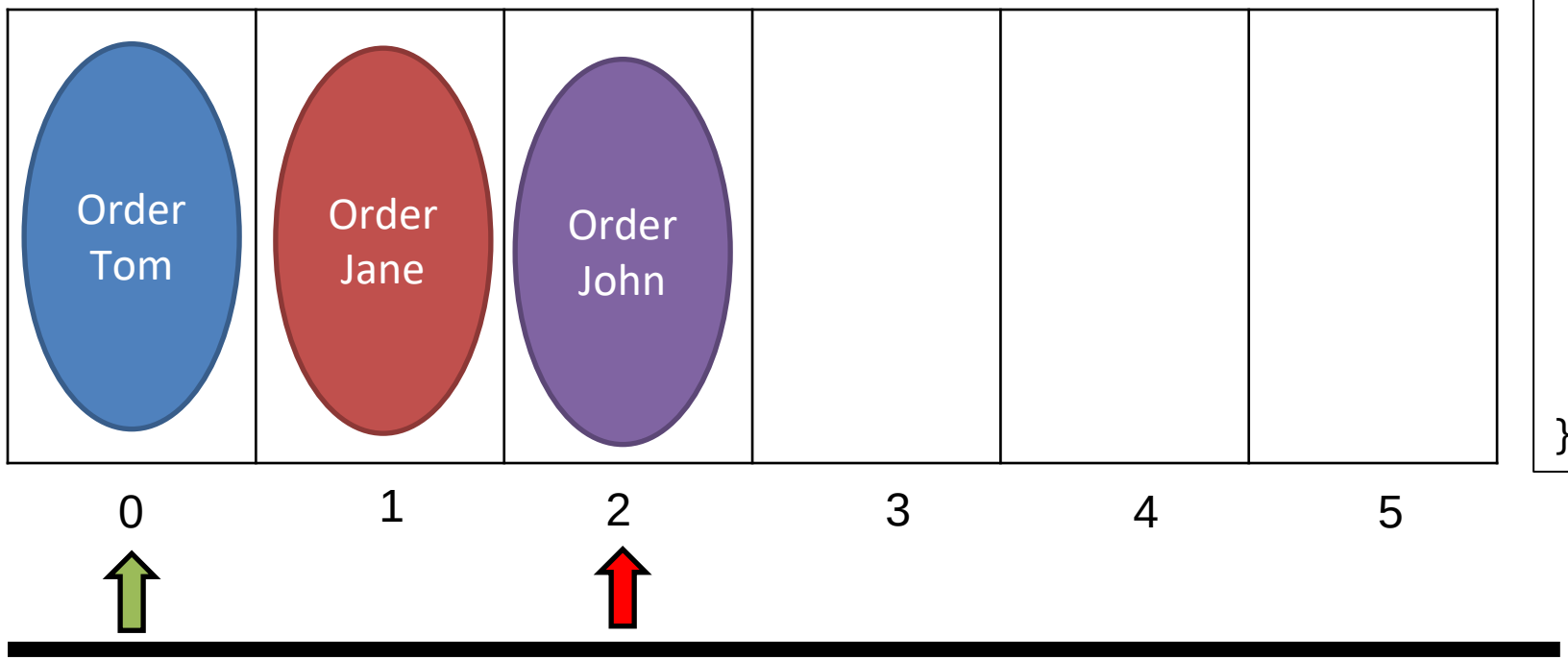


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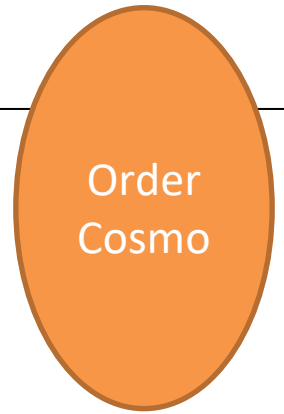


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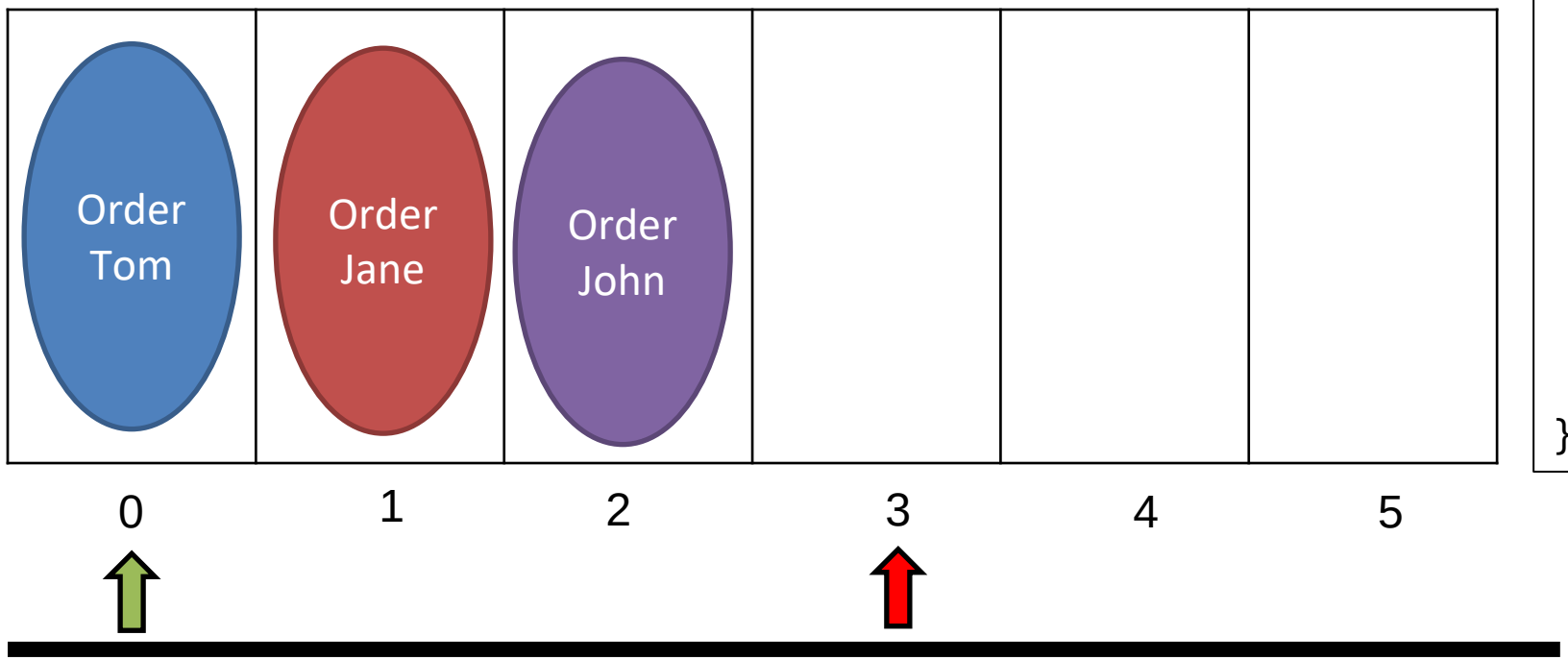


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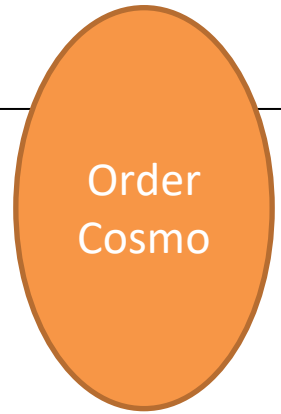


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capacity = 6    front = 0
size = 3        rear = 3
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Today, we will be implementing a Queue with an Array.

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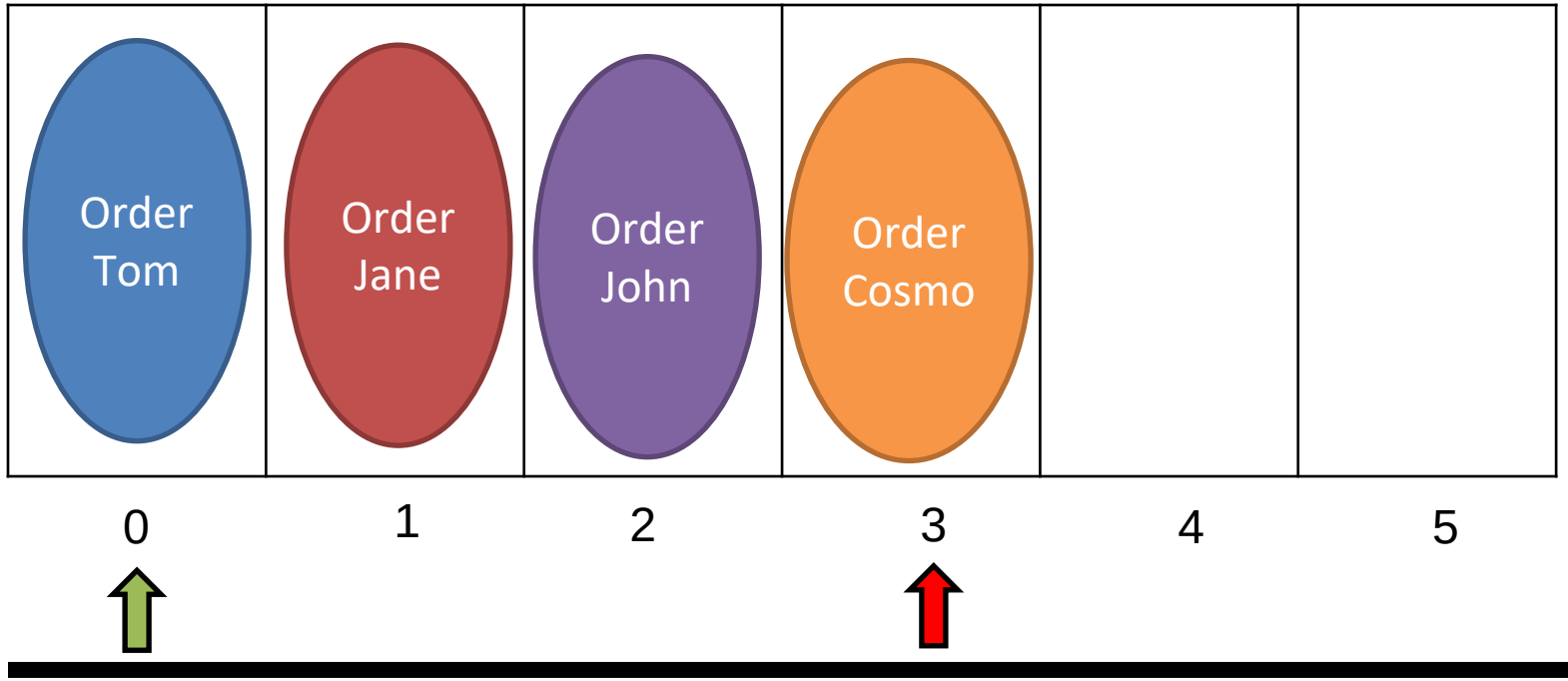


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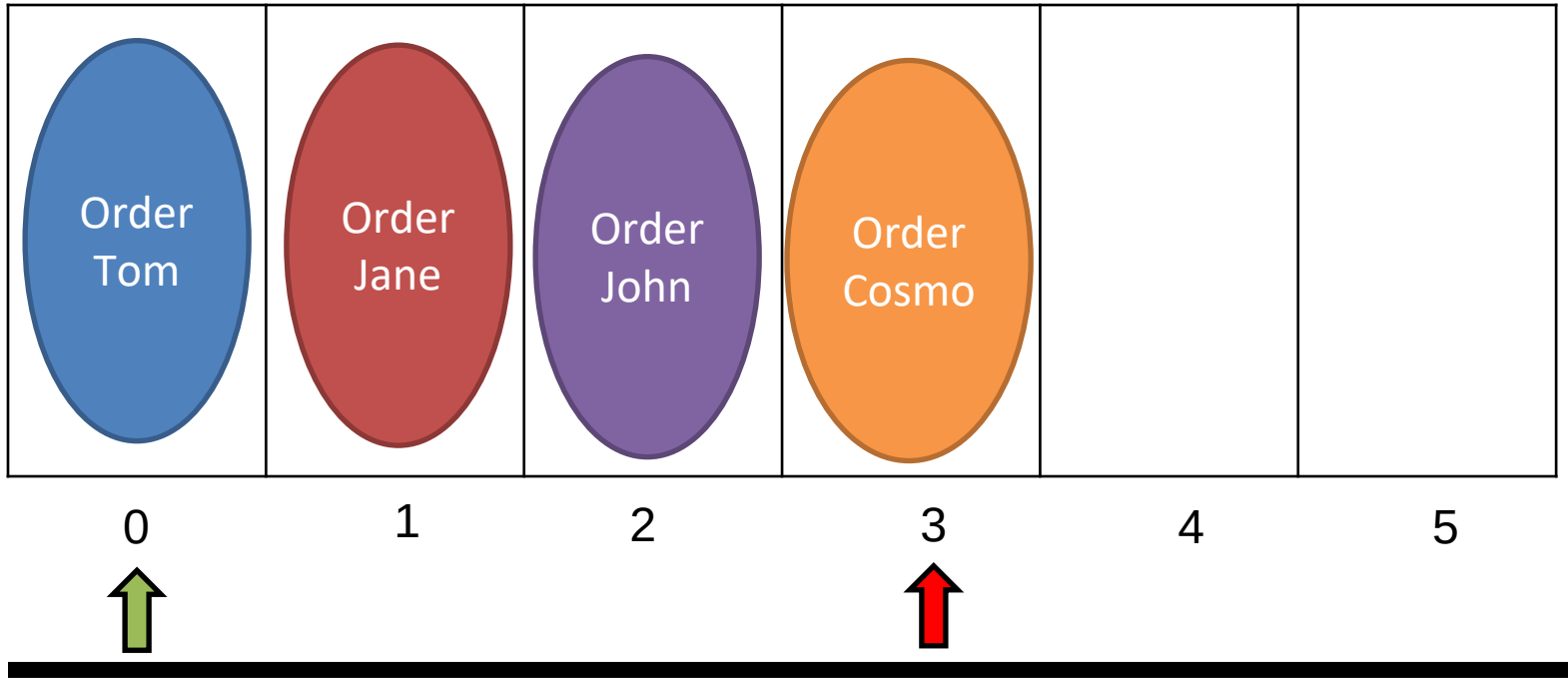


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```

capacity = 6 front = 0

size = 4 rear = 3

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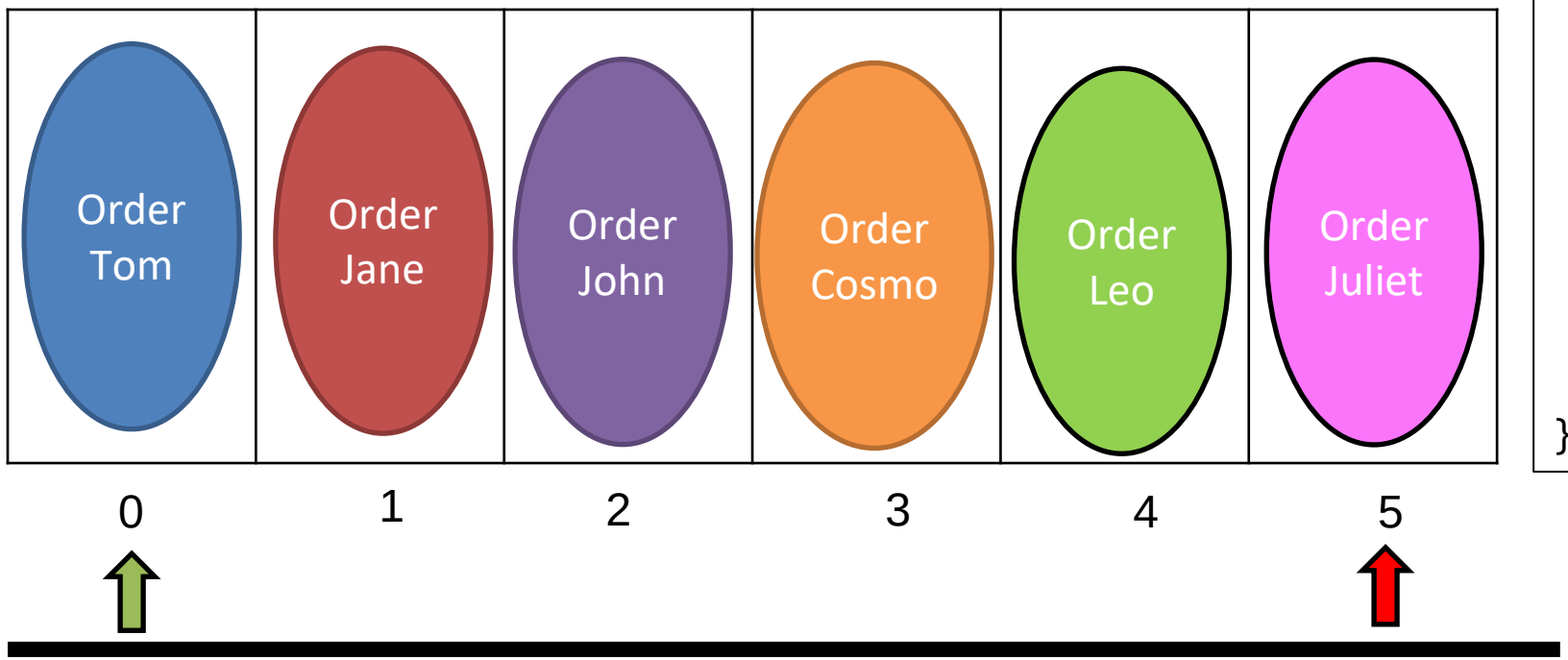


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  }
}
```

```
capacity = 6    front = 0
size = 6        rear = 5
```

Issues with this?

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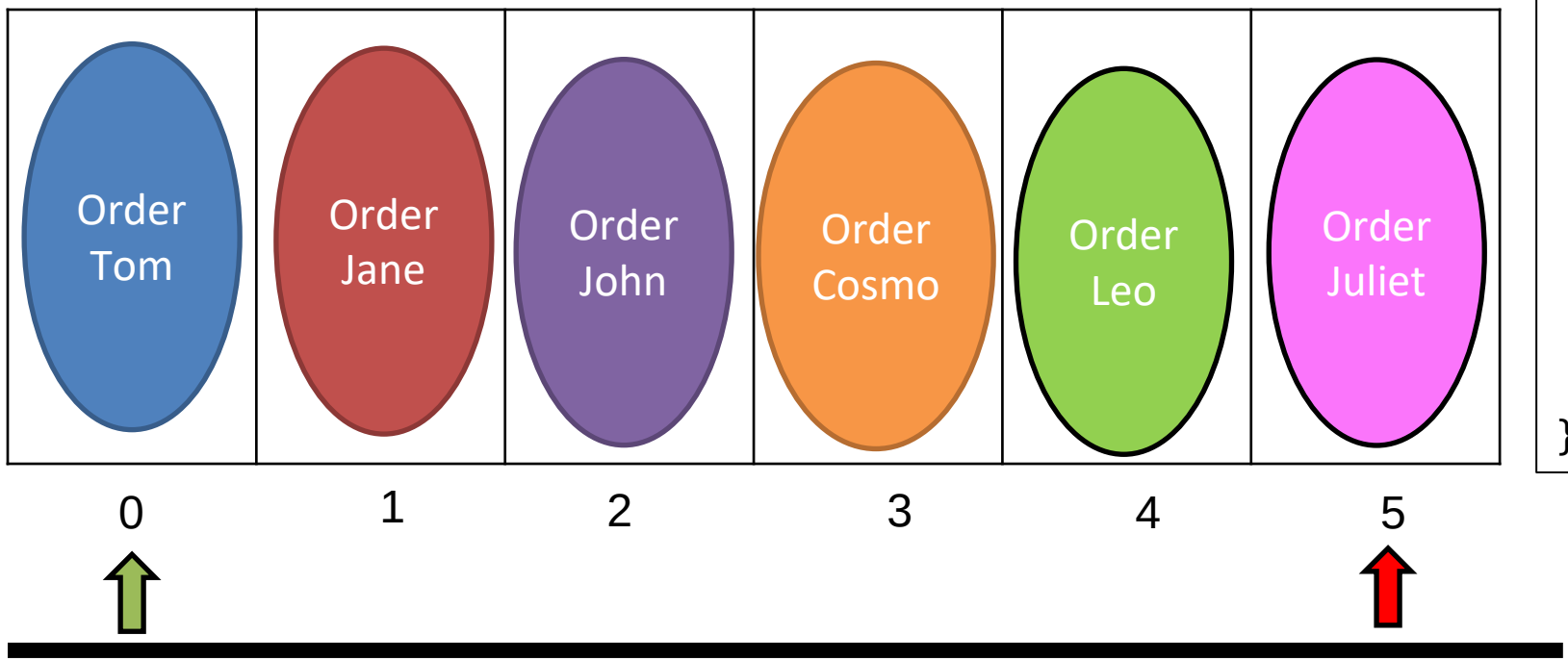


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   }
}
```

This if statement is not satisfied, so we will try to add to a full queue → Array index out of bounds

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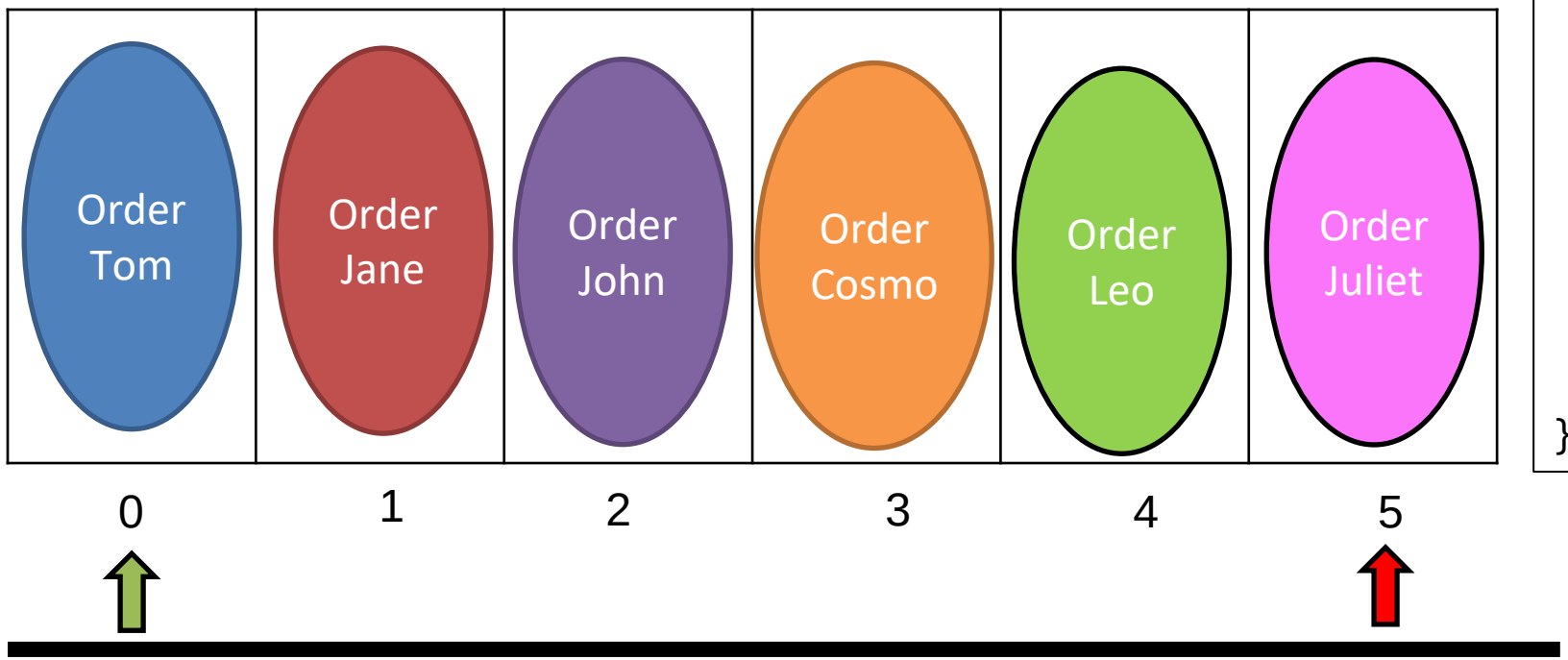


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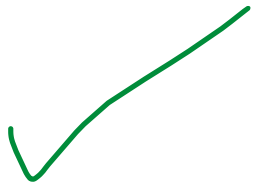

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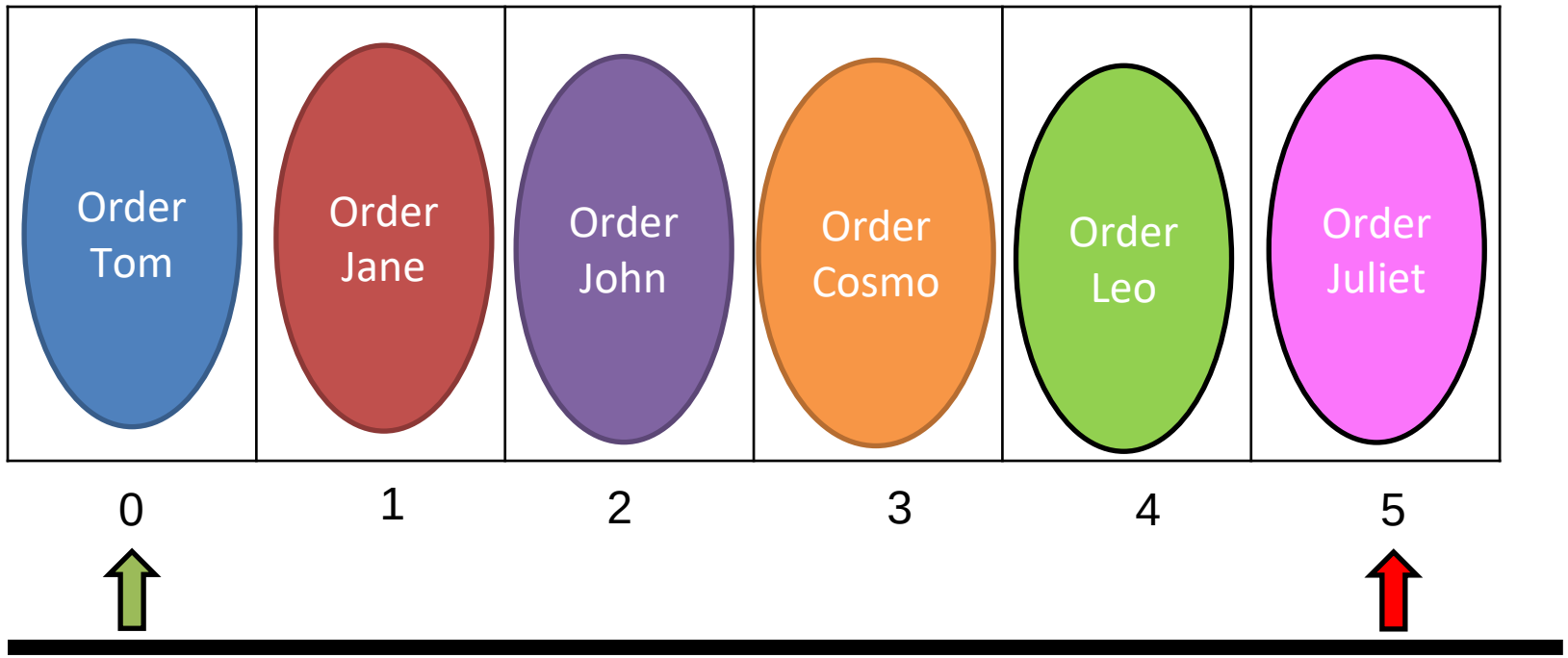

Dequeue?

```
capacity = 6    front = 0
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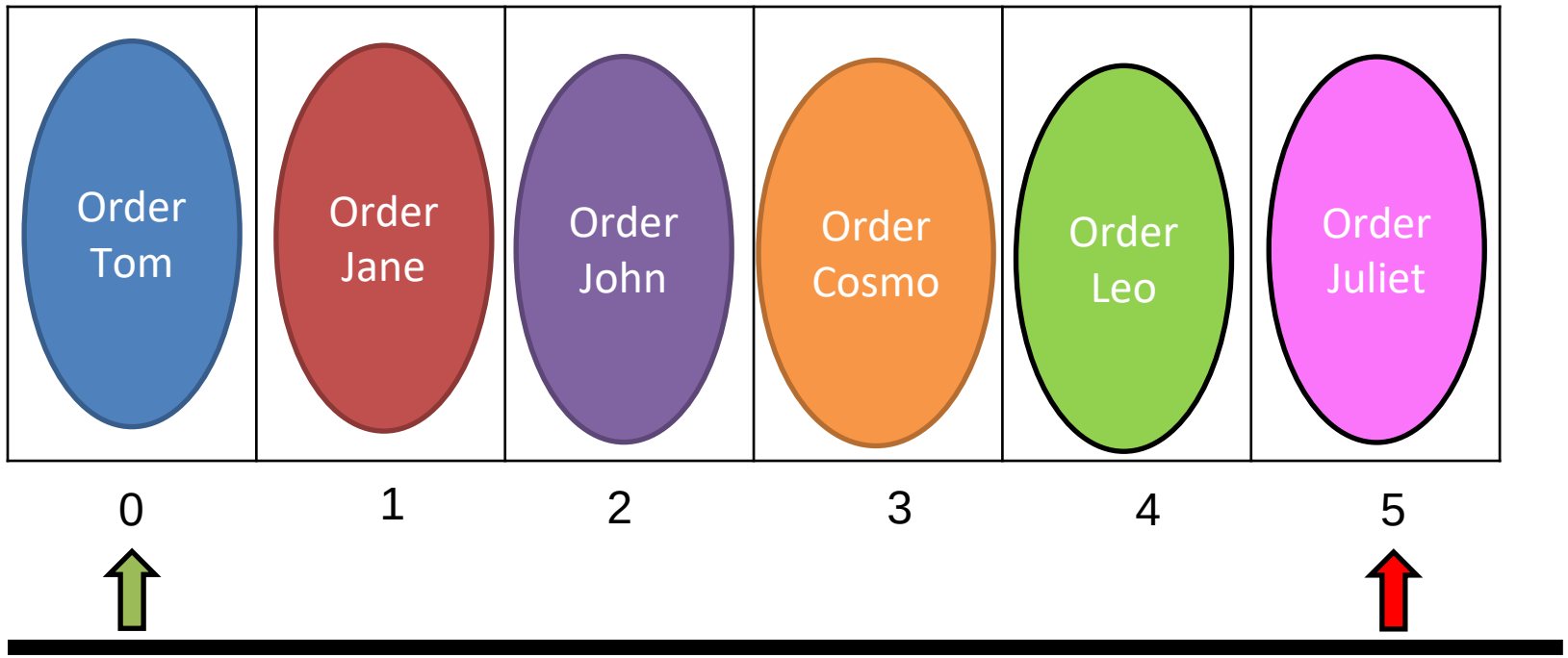

Remove the front element, move front pointer forward one spot

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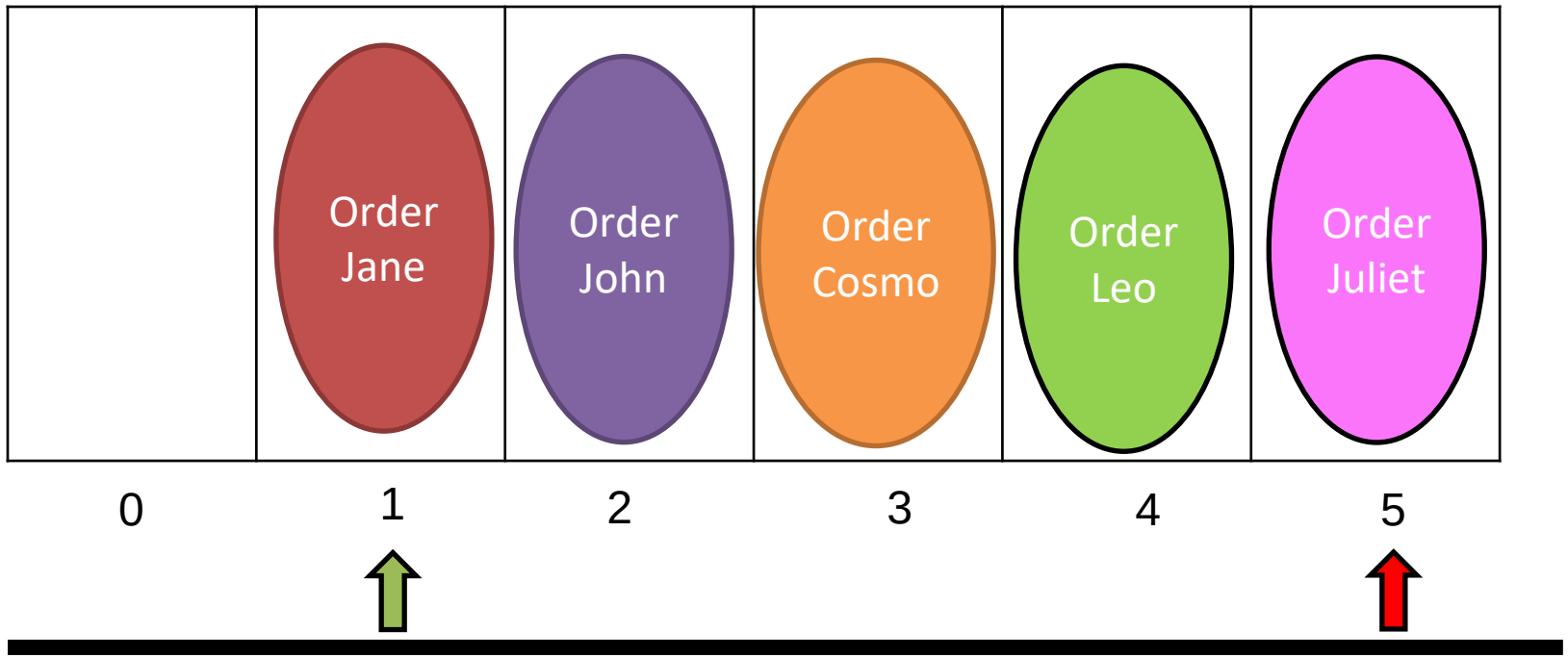

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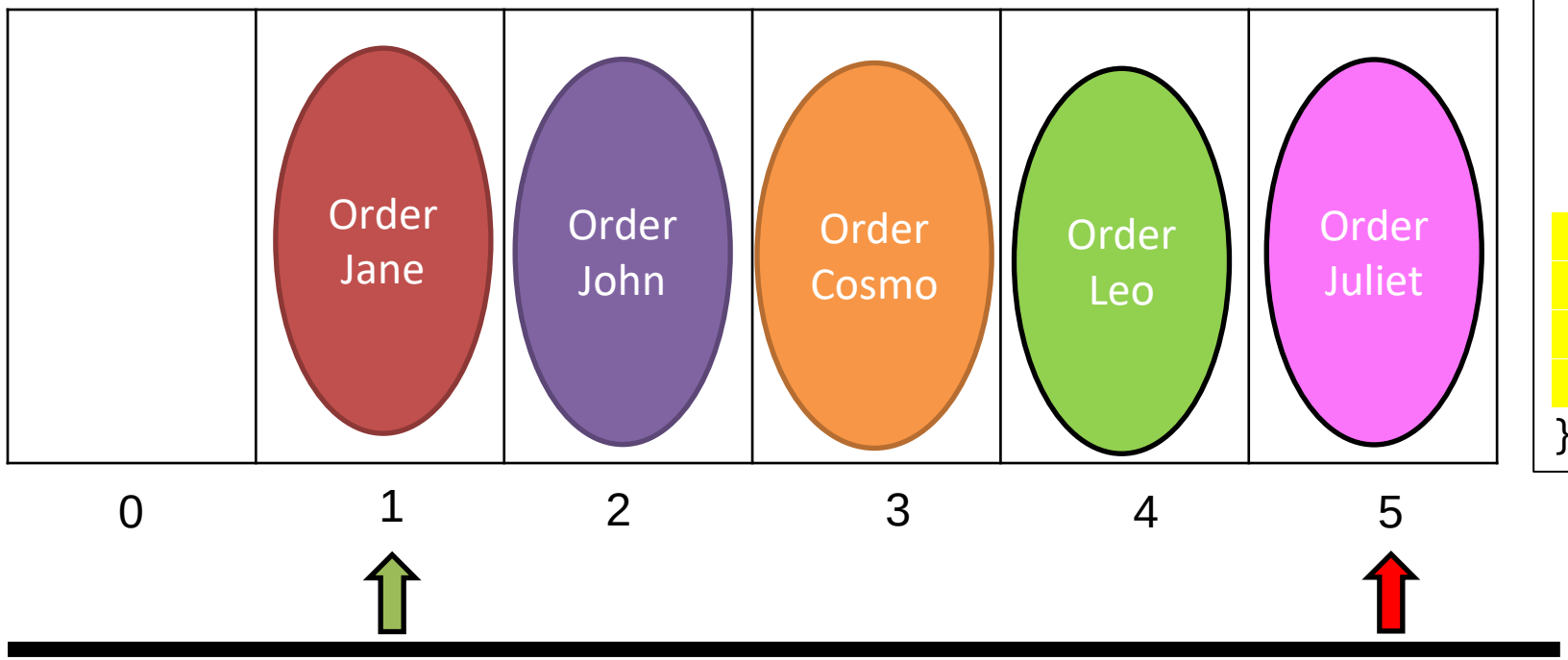

Enqueue again?

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public void enqueue(Order newOrder) {
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  else {
    rear++;
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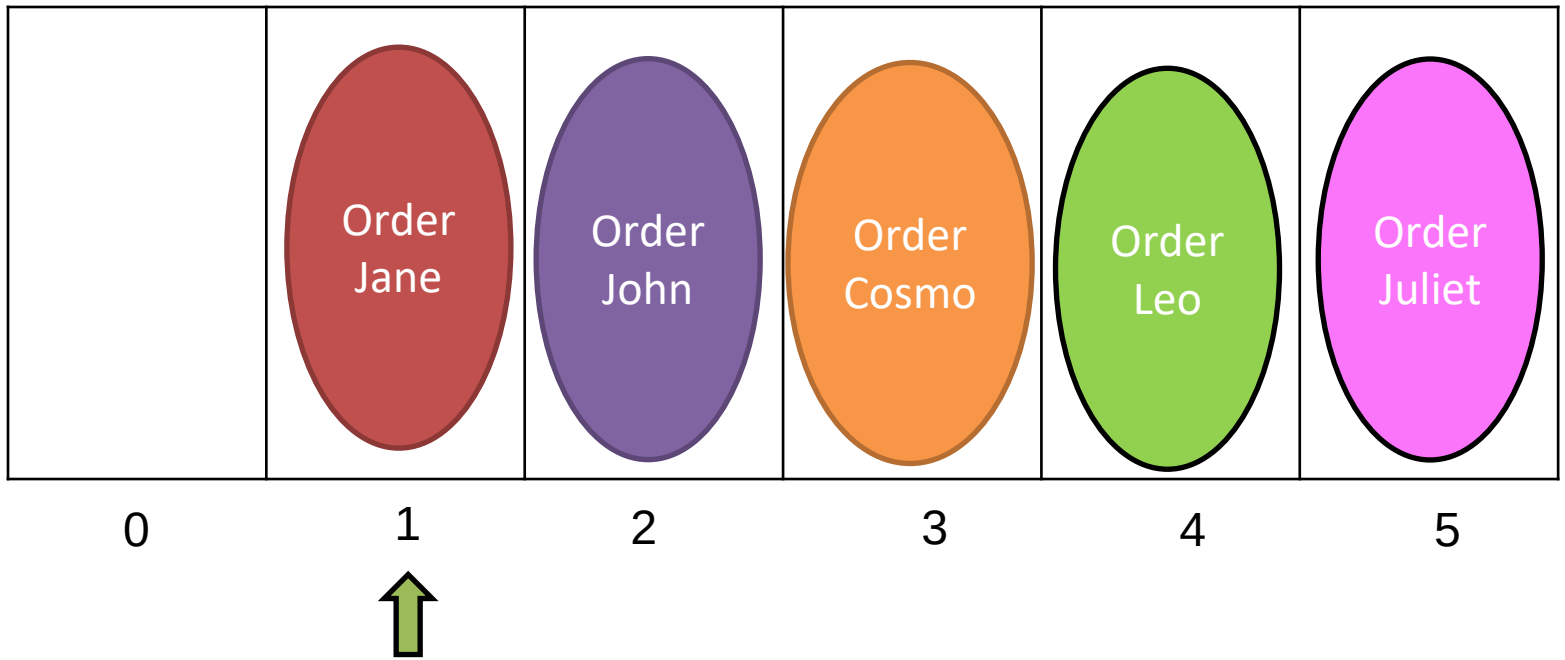

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```

Array index out of bounds error!

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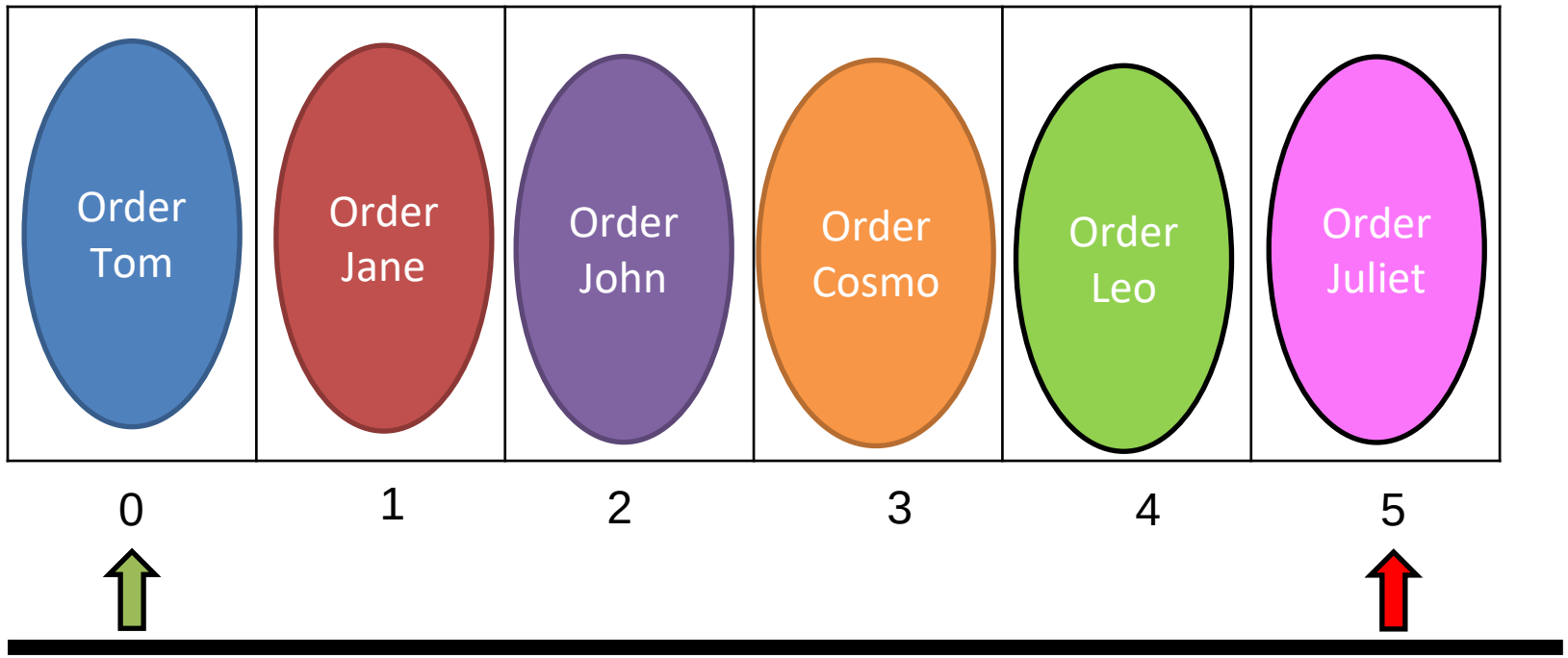

Dequeue?

1. Remove the front element
2. Make some room in the back

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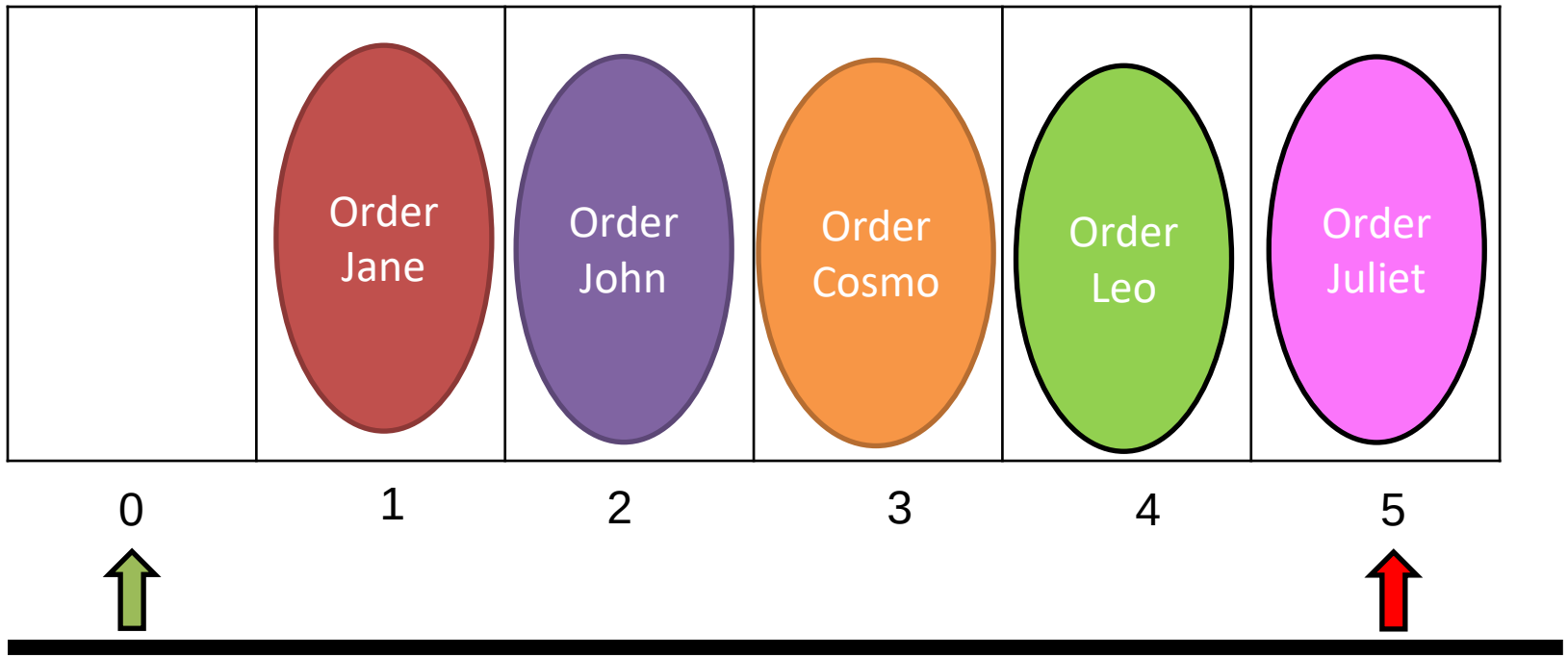

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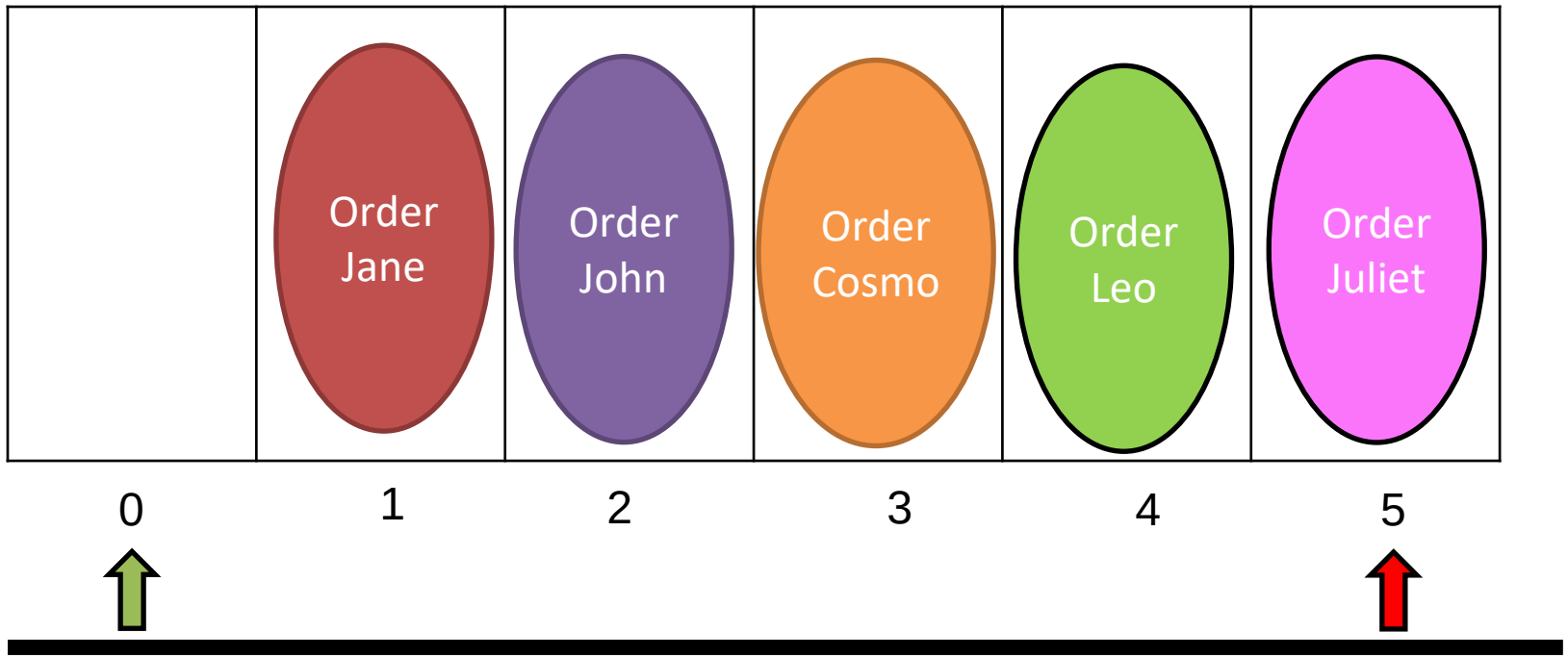

Dequeue?

1. Remove the front element
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Shift all of our data over one spot

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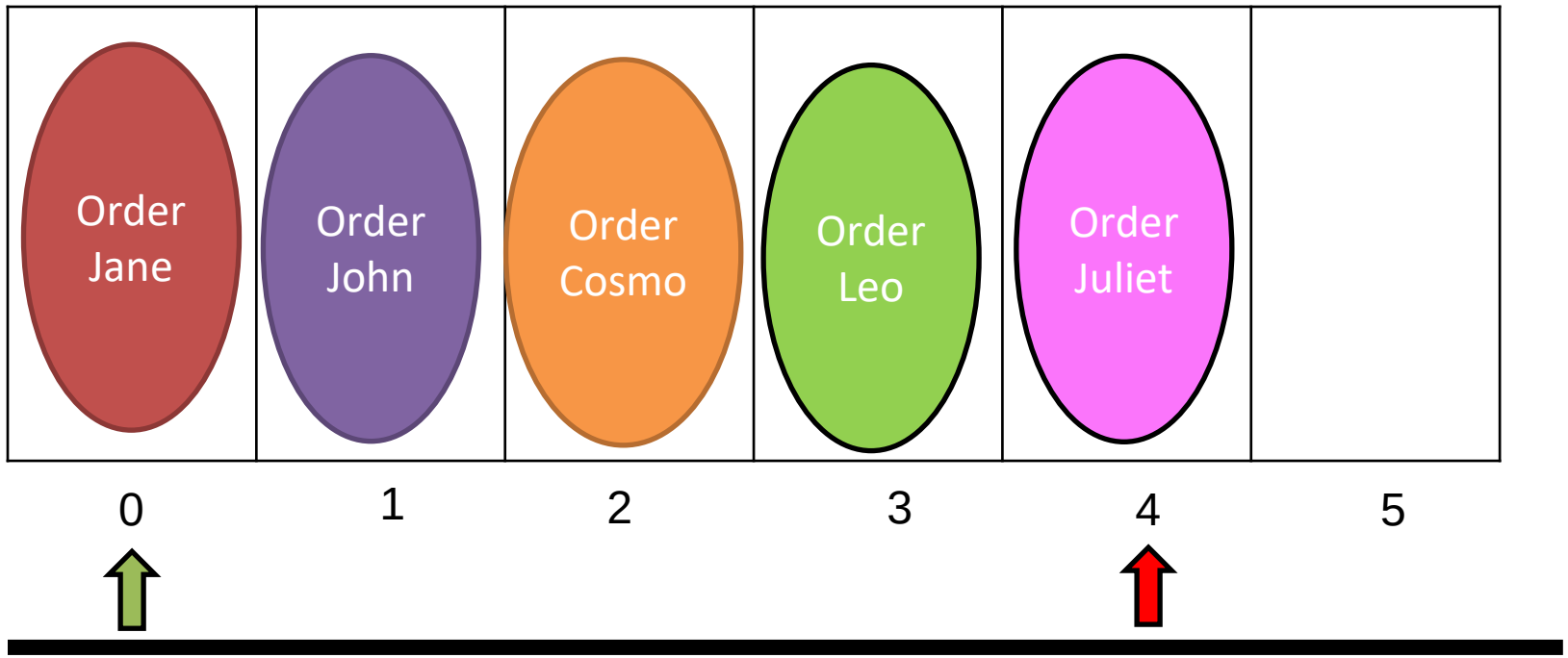

Dequeue?

1. Remove the front element
2. Make some room in the back

Shift all of our data over one spot

The `front` of our queue will **always** stay at zero

```
capacity = 6    front = 0
size = 5        rear = 4
```

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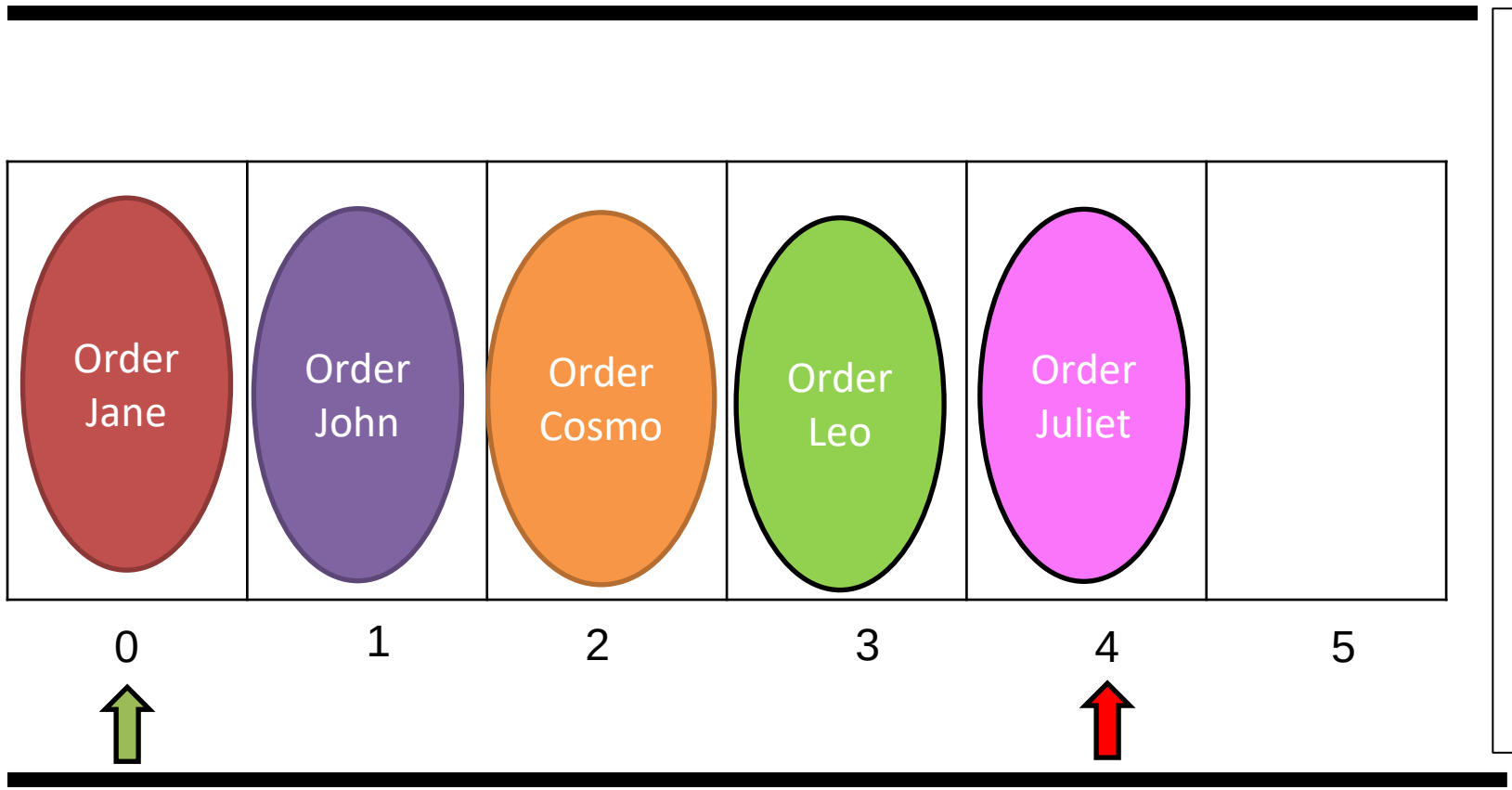


```
public void dequeue() {
 if(this.size == 0) {
   System.out.println("empty...");
   return;
 }
 else {
   for(int i = 0; i < back-1; i++) {
      this.orders[i] = this.orders[i+1];
   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

`capacity = 6` `front = 0`

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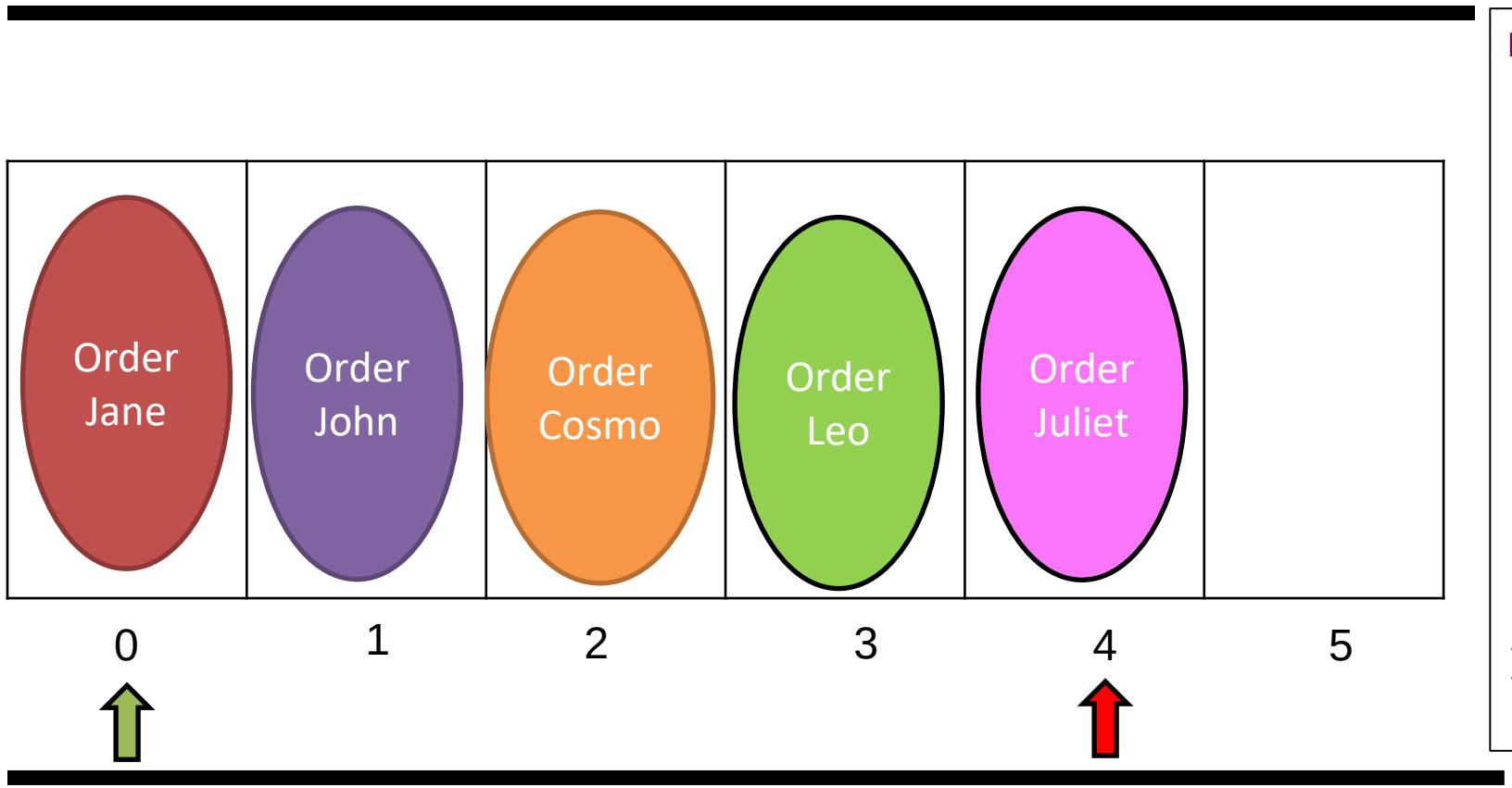


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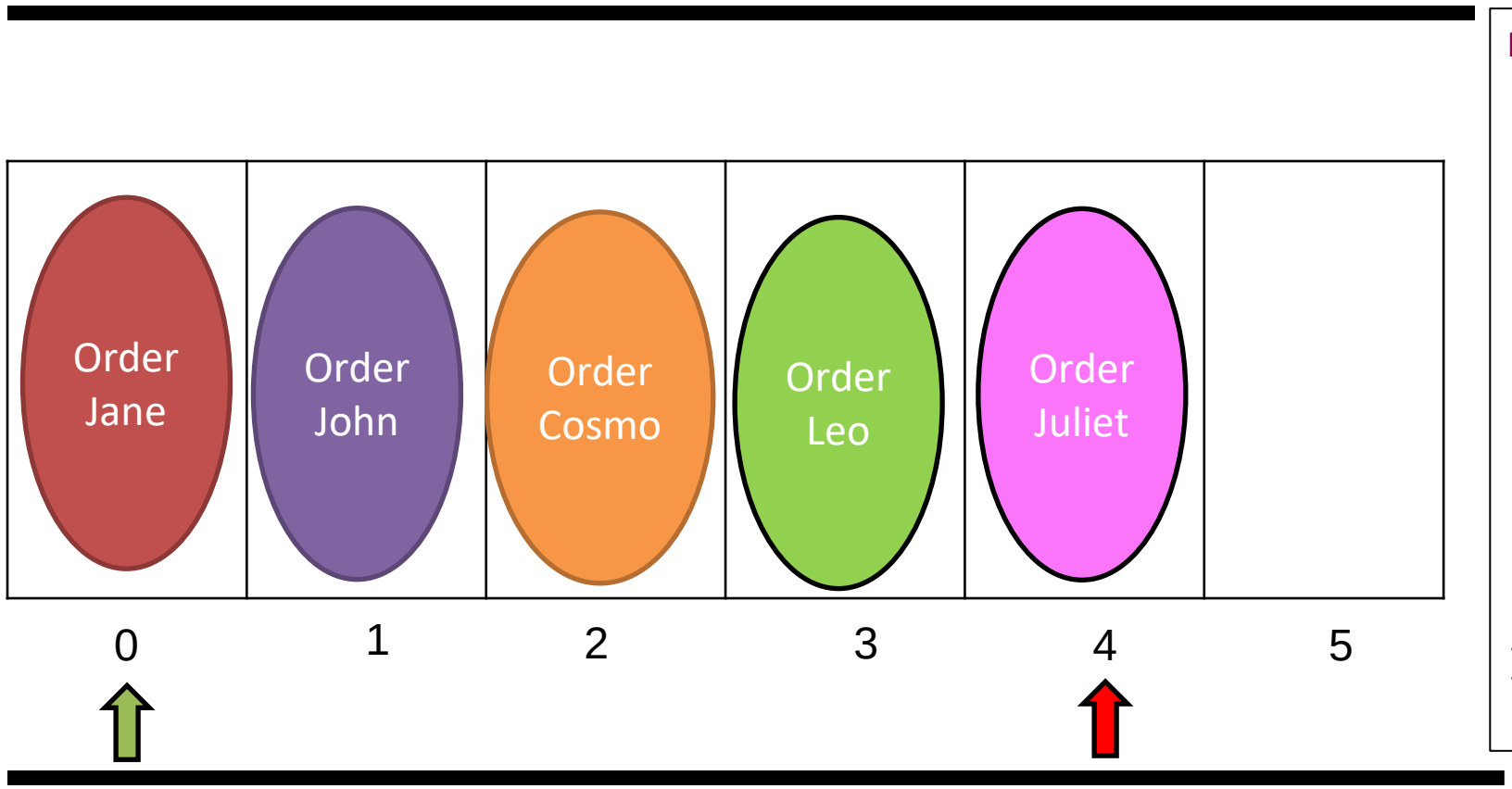
   }
   this.back--;
   this.size--;
 }
}
```

```
capacity = 6    front = 0
size = 5        rear = 4
```

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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 else {
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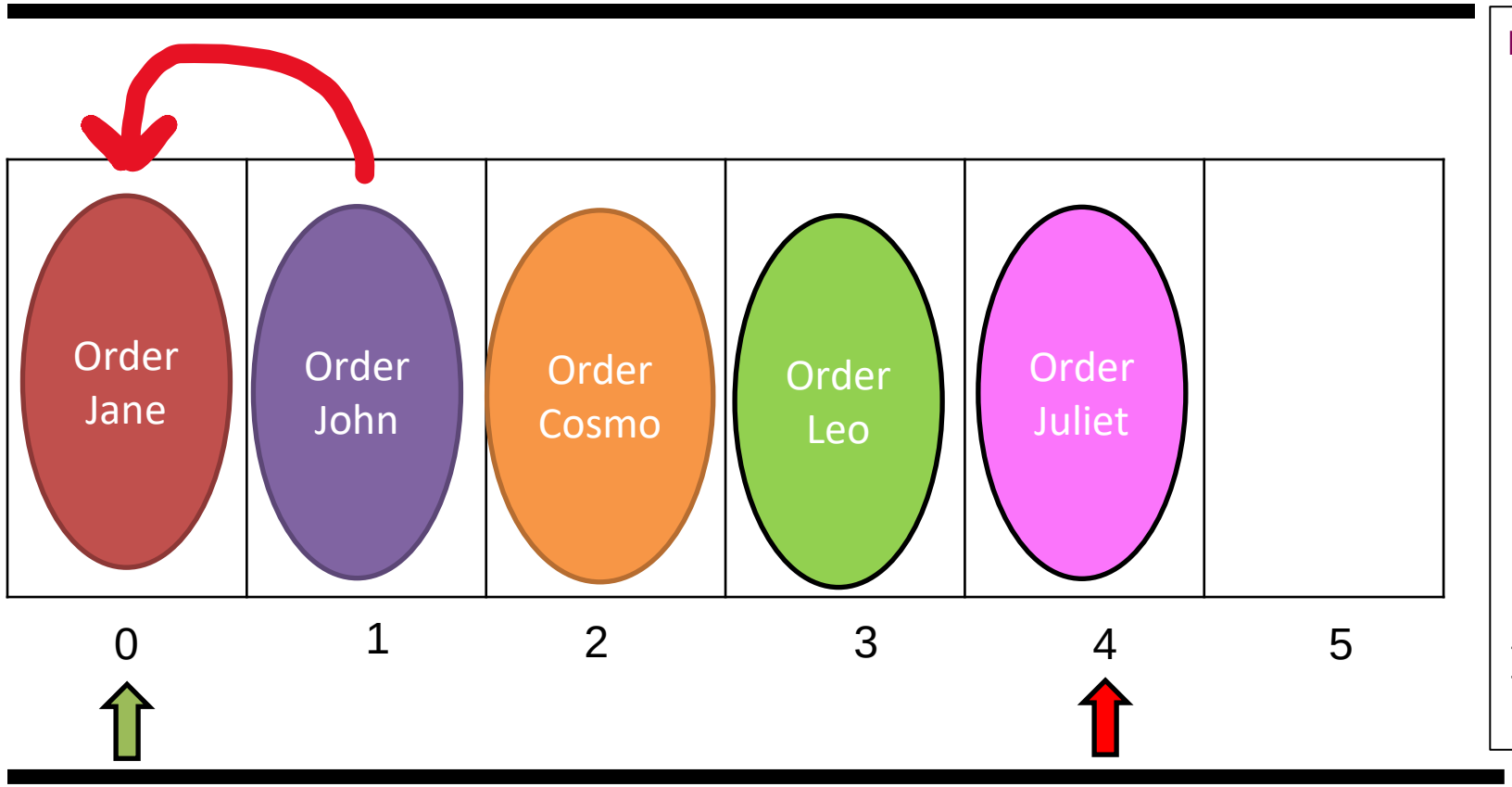
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

`capacity = 6` `front = 0`
`size = 5` `rear = 4`

Shift everything over one spot

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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 }
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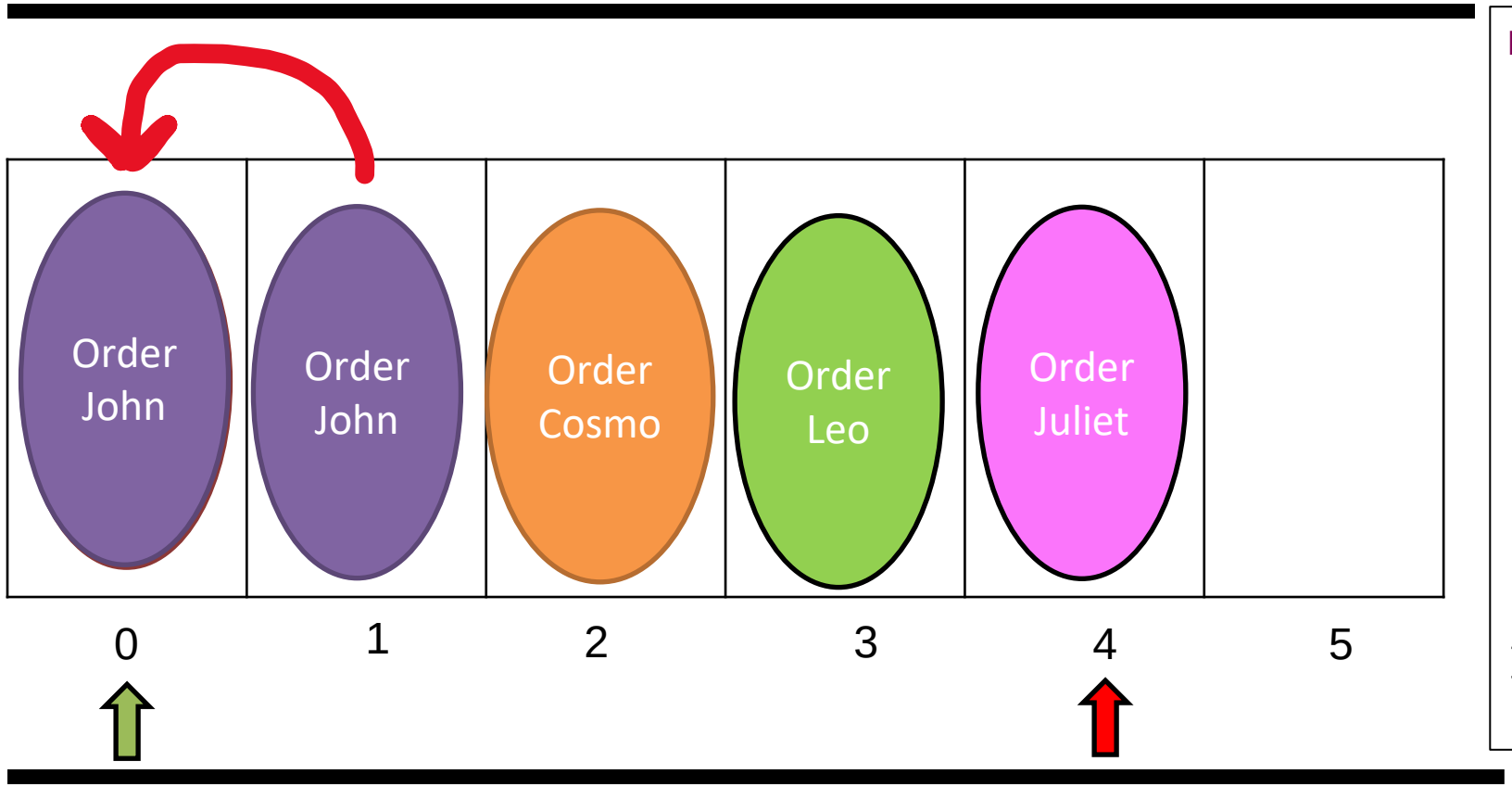
   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

```
capacity = 6    front = 0
size = 5        rear = 4
```

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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public void dequeue() {
 if(this.size == 0) {
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   return;
 }
 else {
   for(int i = 0; i < back-1; i++) {
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   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
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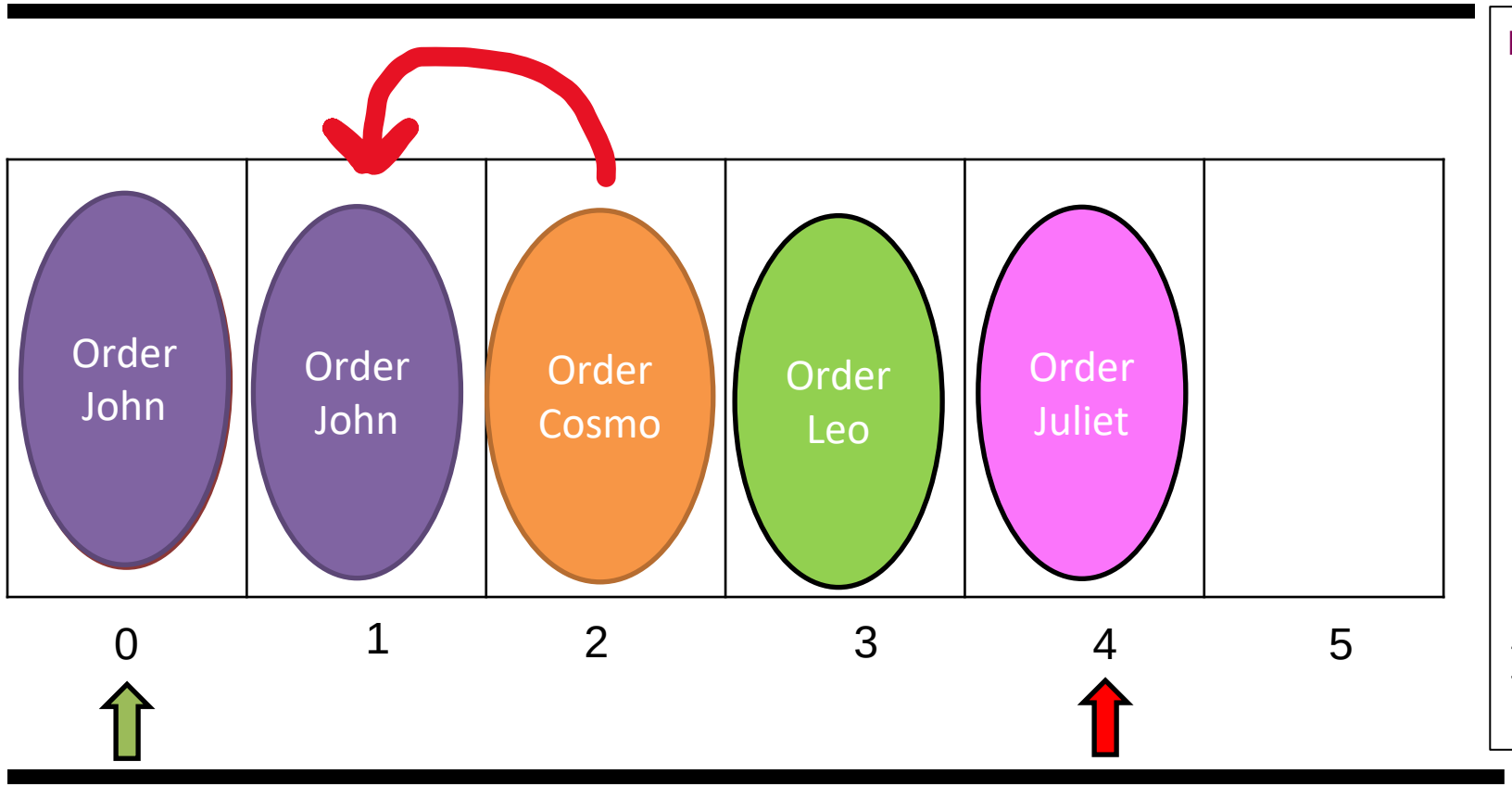
 }
}
```

`capacity = 6` `front = 0`

`size = 5` `rear = 4`

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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   return;
 }
 else {
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   }
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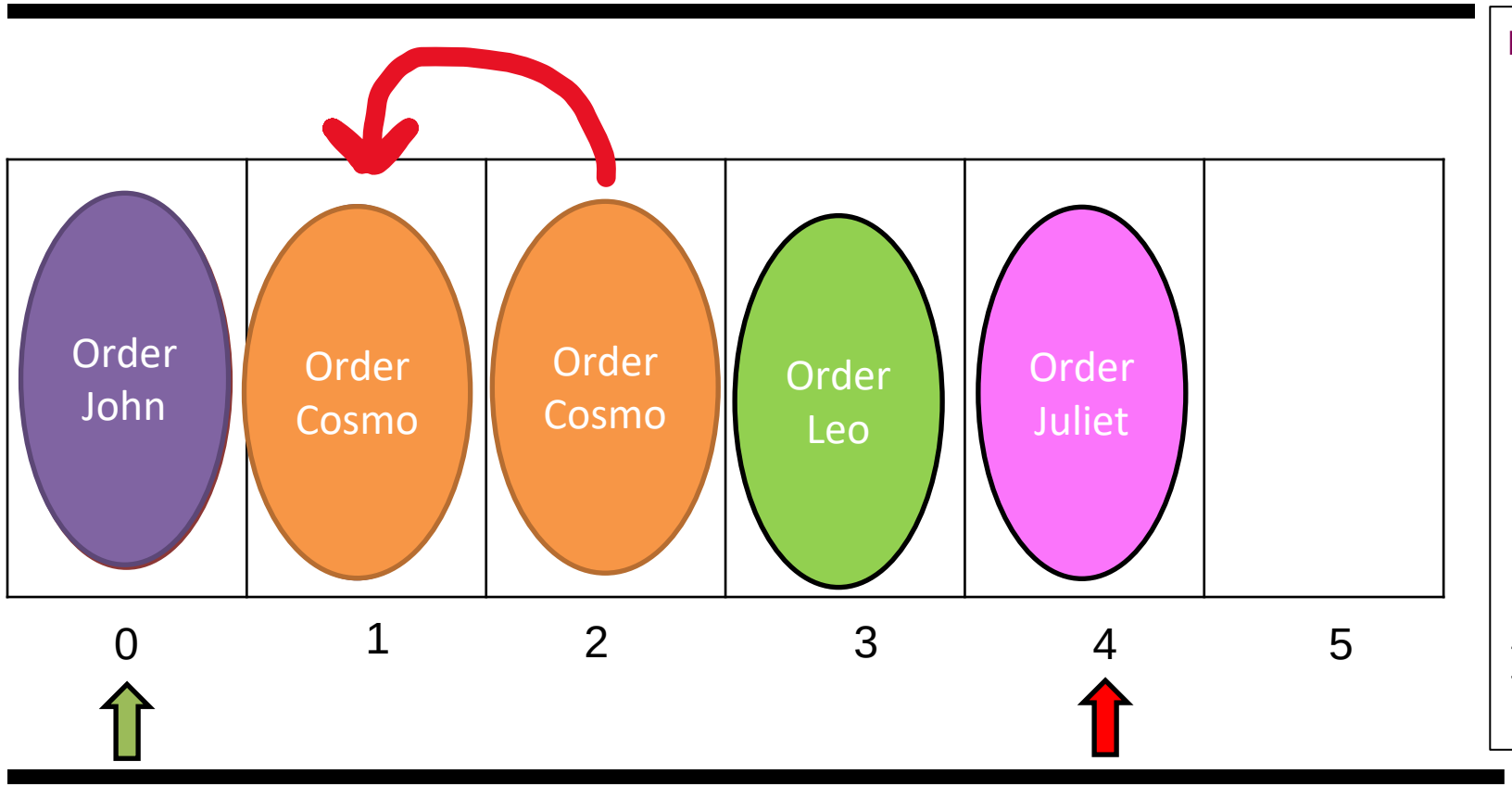
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

`capacity = 6` `front = 0`

`size = 5` `rear = 4`

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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   return;
 }
 else {
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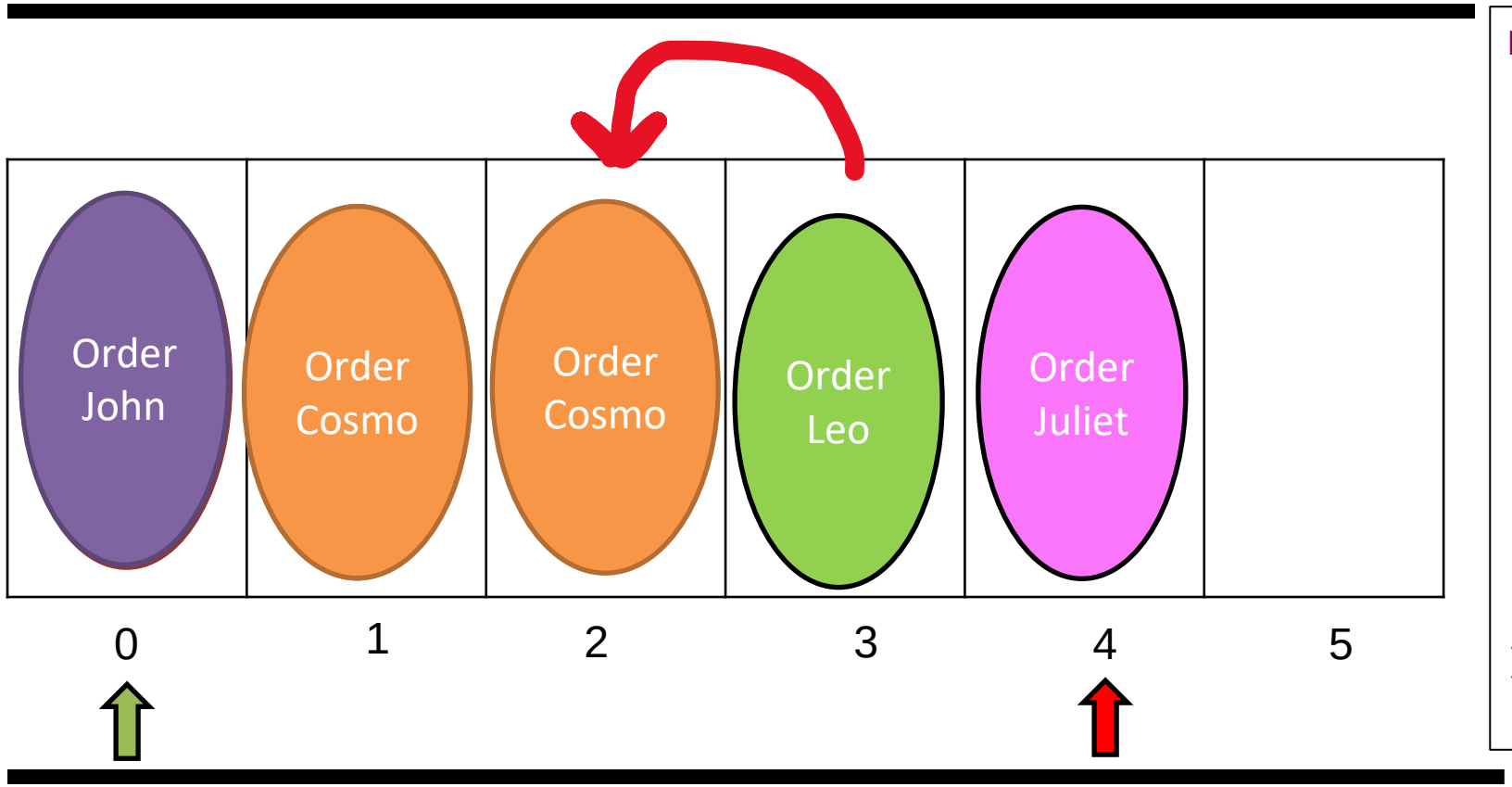
   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

```
capacity = 6    front = 0
size = 5        rear = 5
```

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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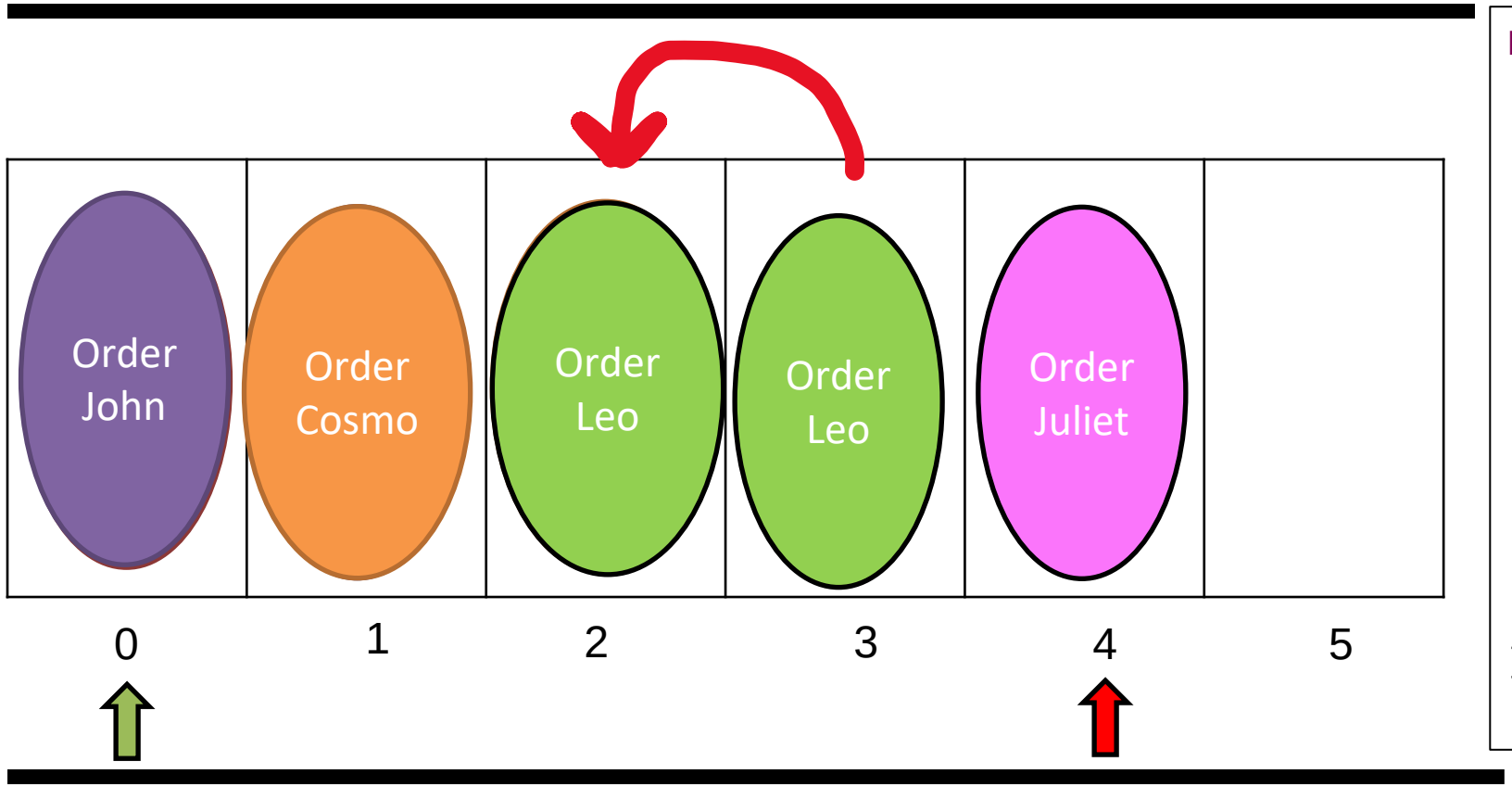
```
capacity = 6    front = 0
size = 5        rear = 4
```

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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   }
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```

`capacity = 6` `front = 0`

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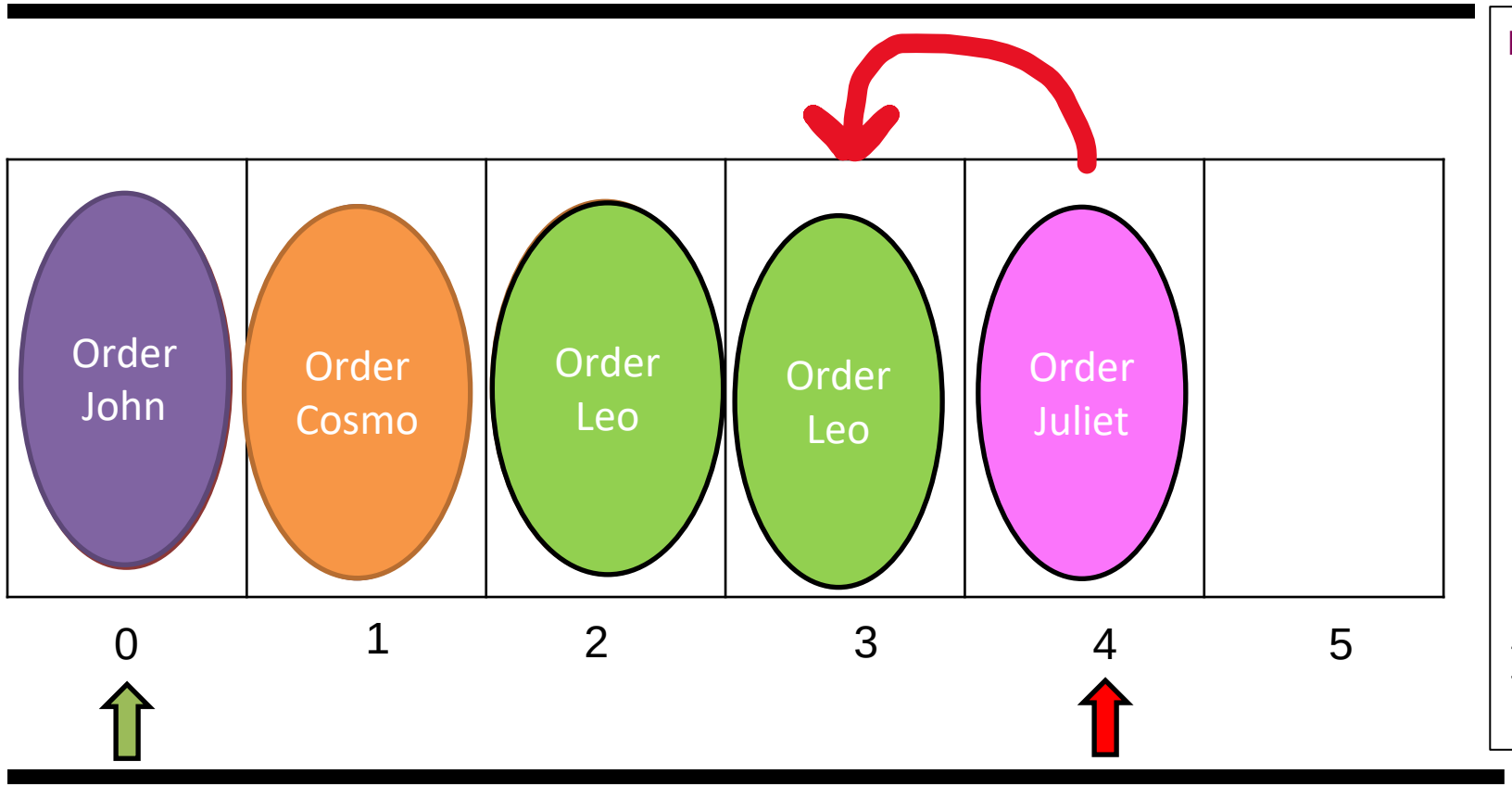
Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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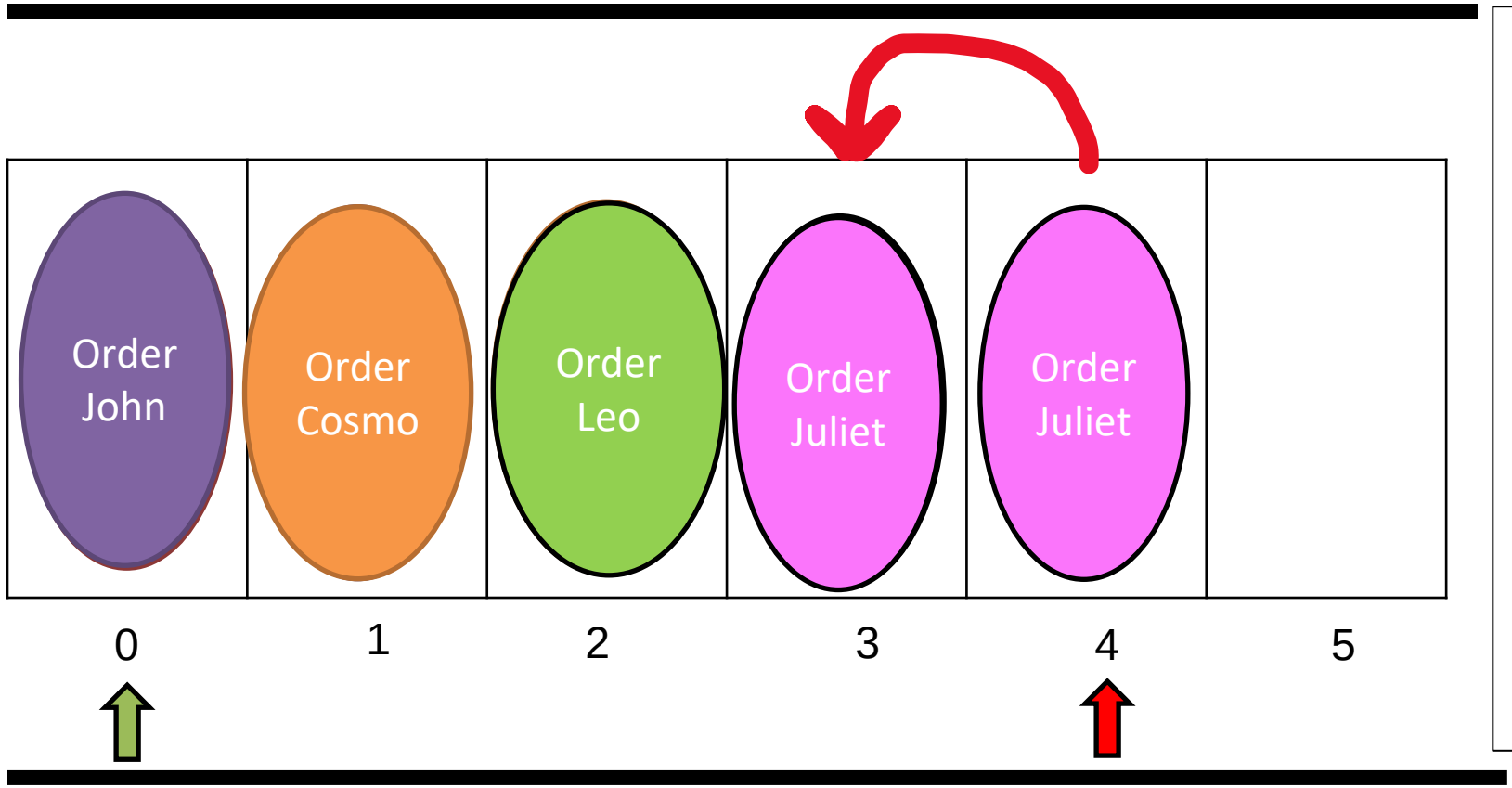
Suppose that we have a queue that can hold 6 elements

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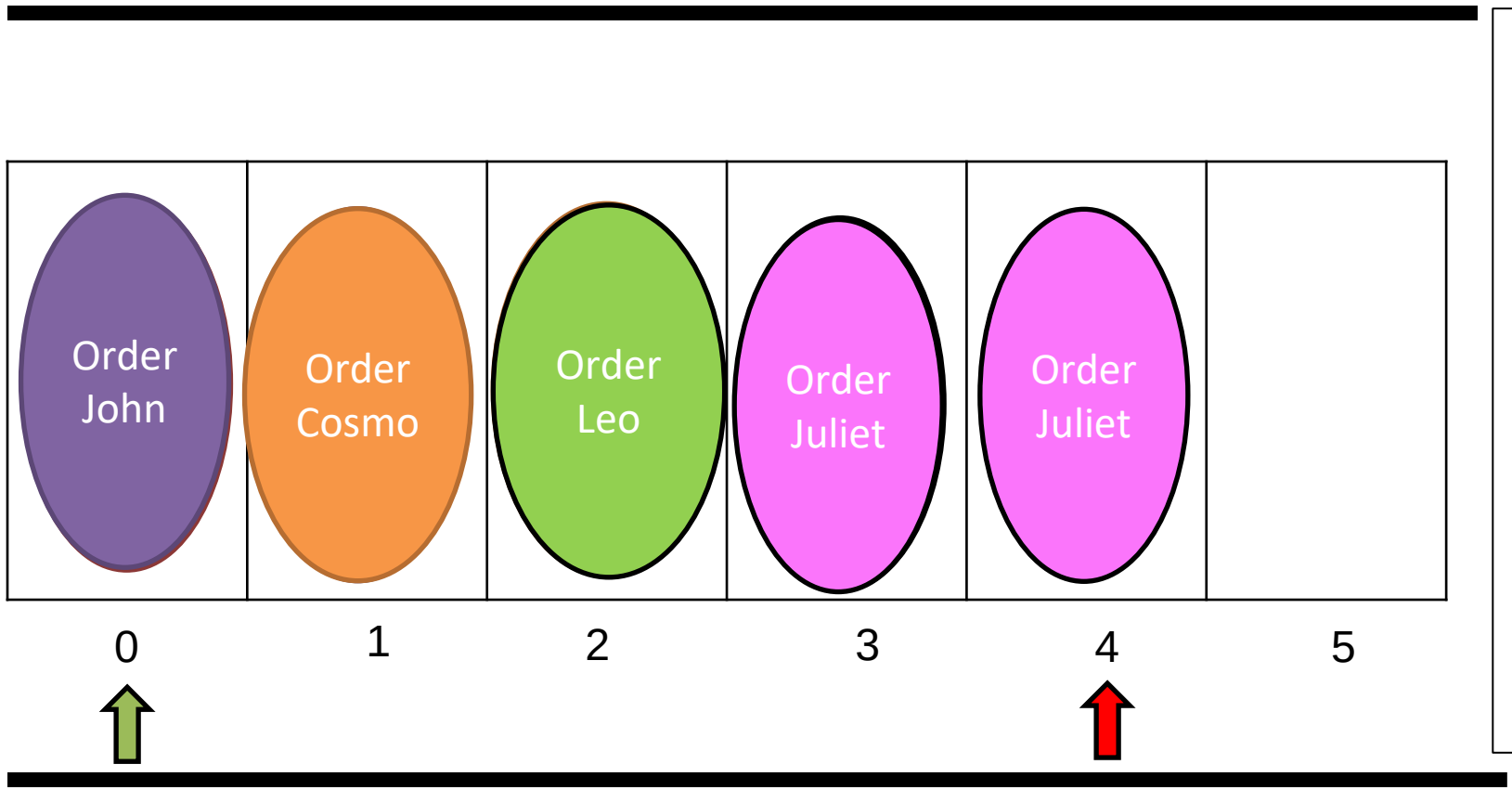


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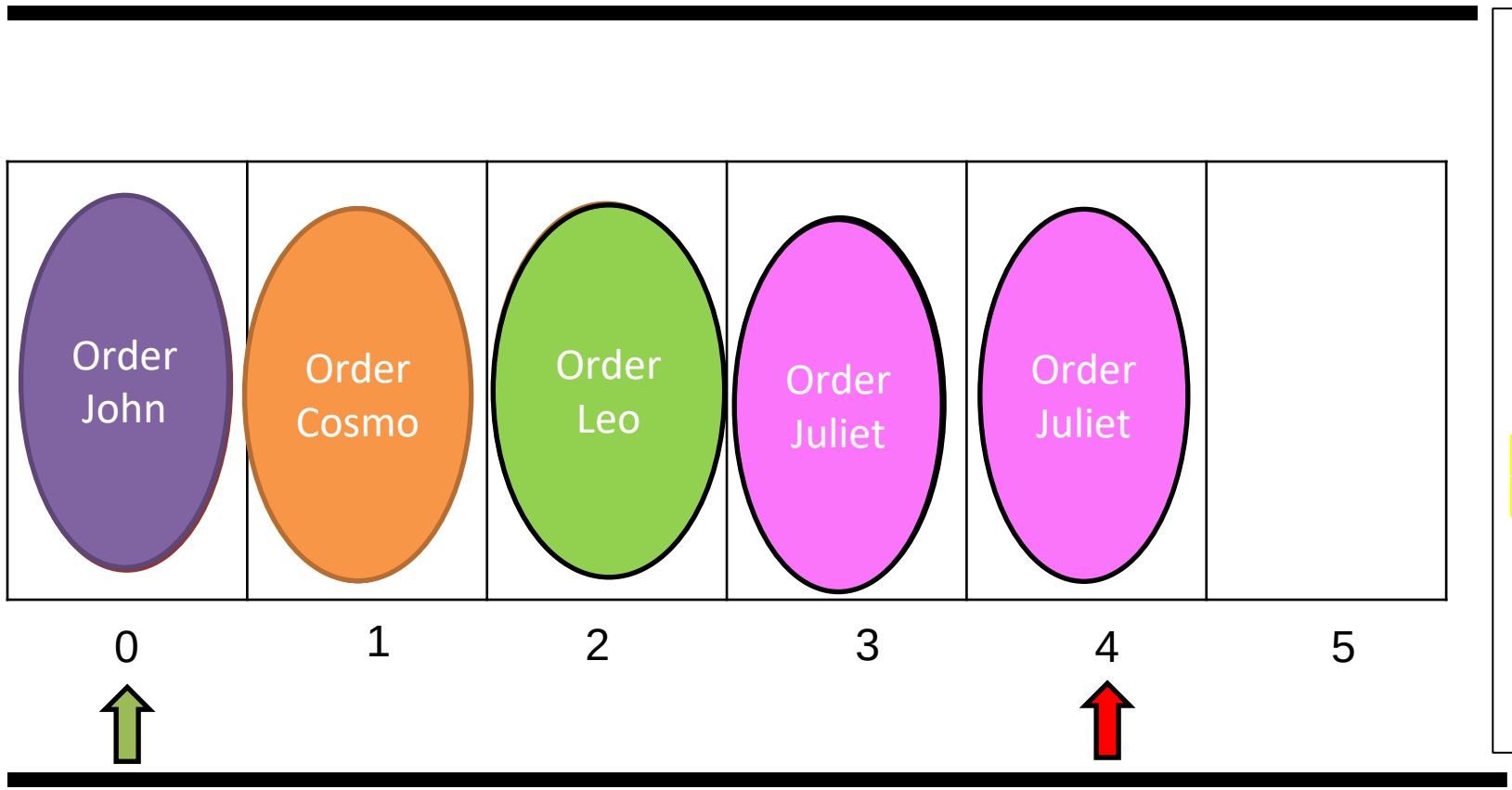


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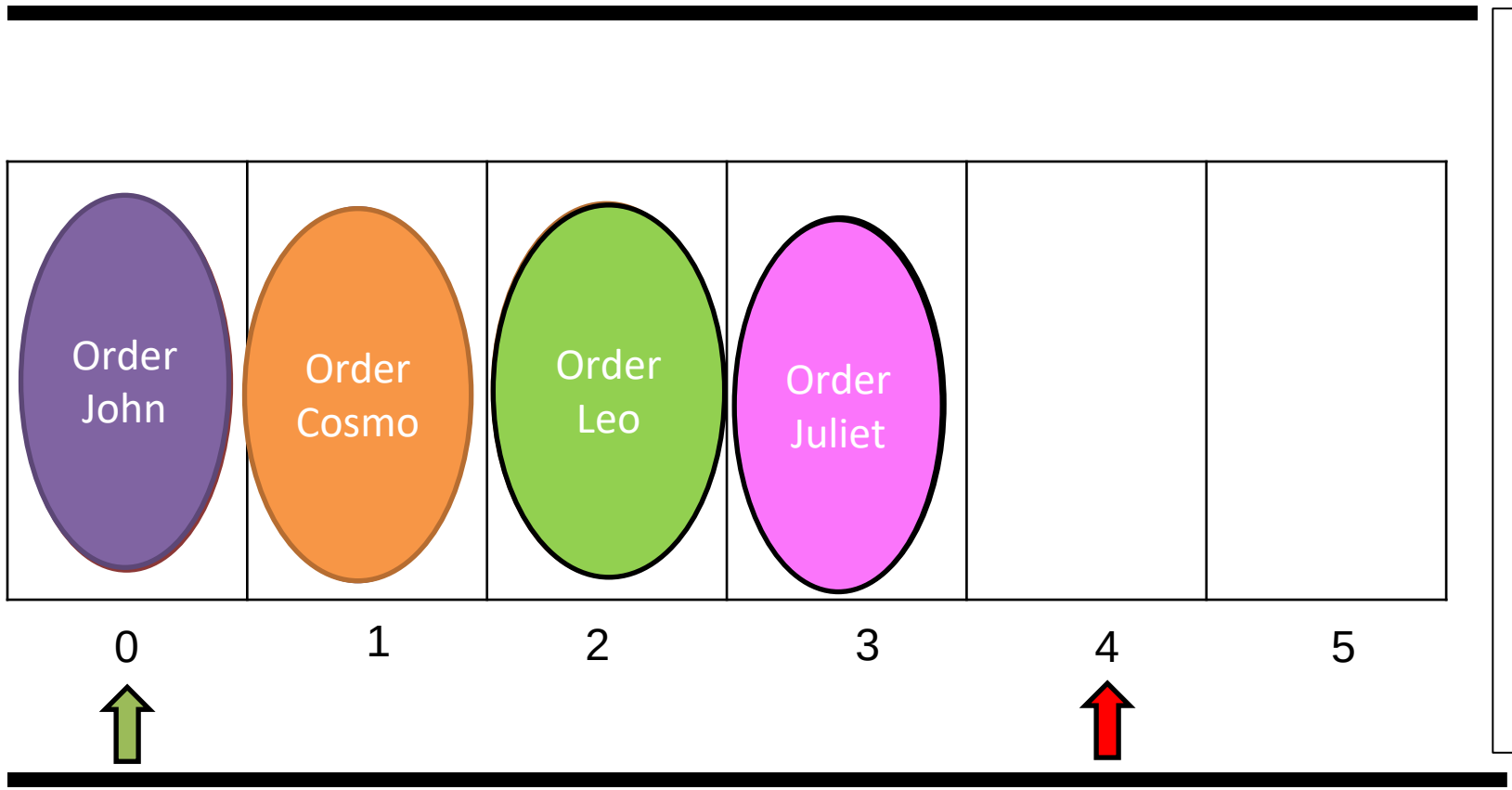


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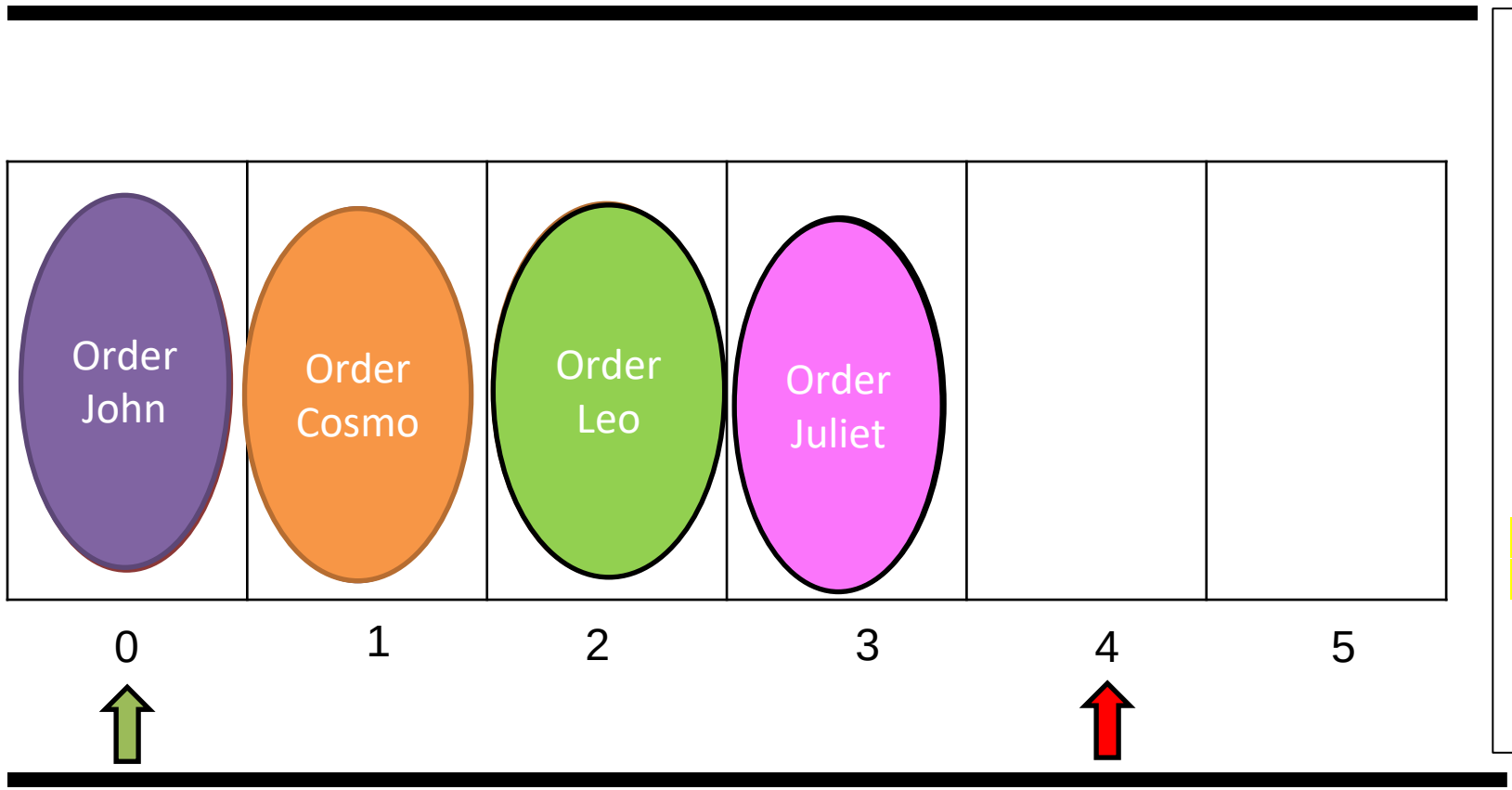
Suppose that we have a queue that can hold 6 elements

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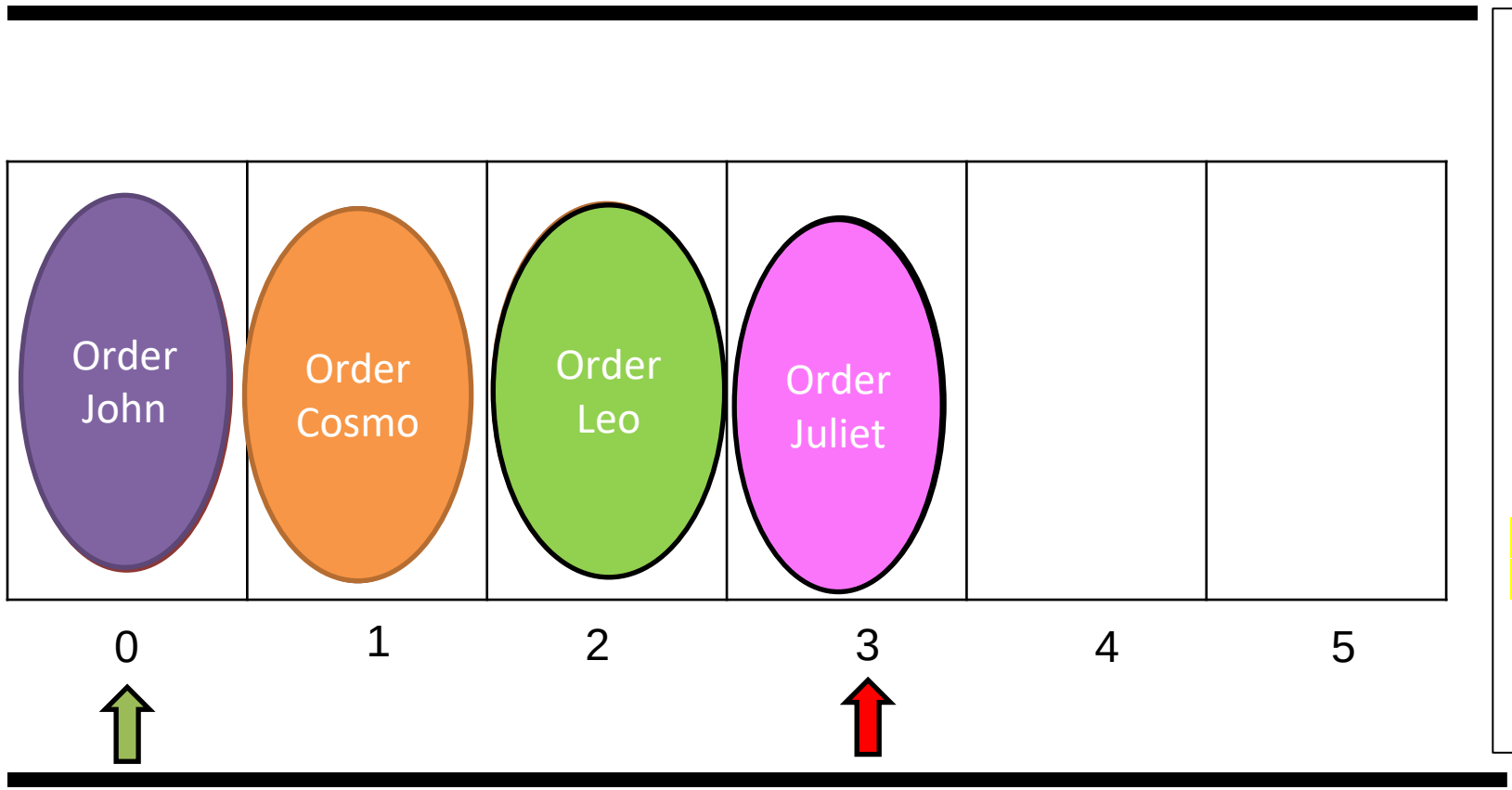
`size = 5` `rear = 4`

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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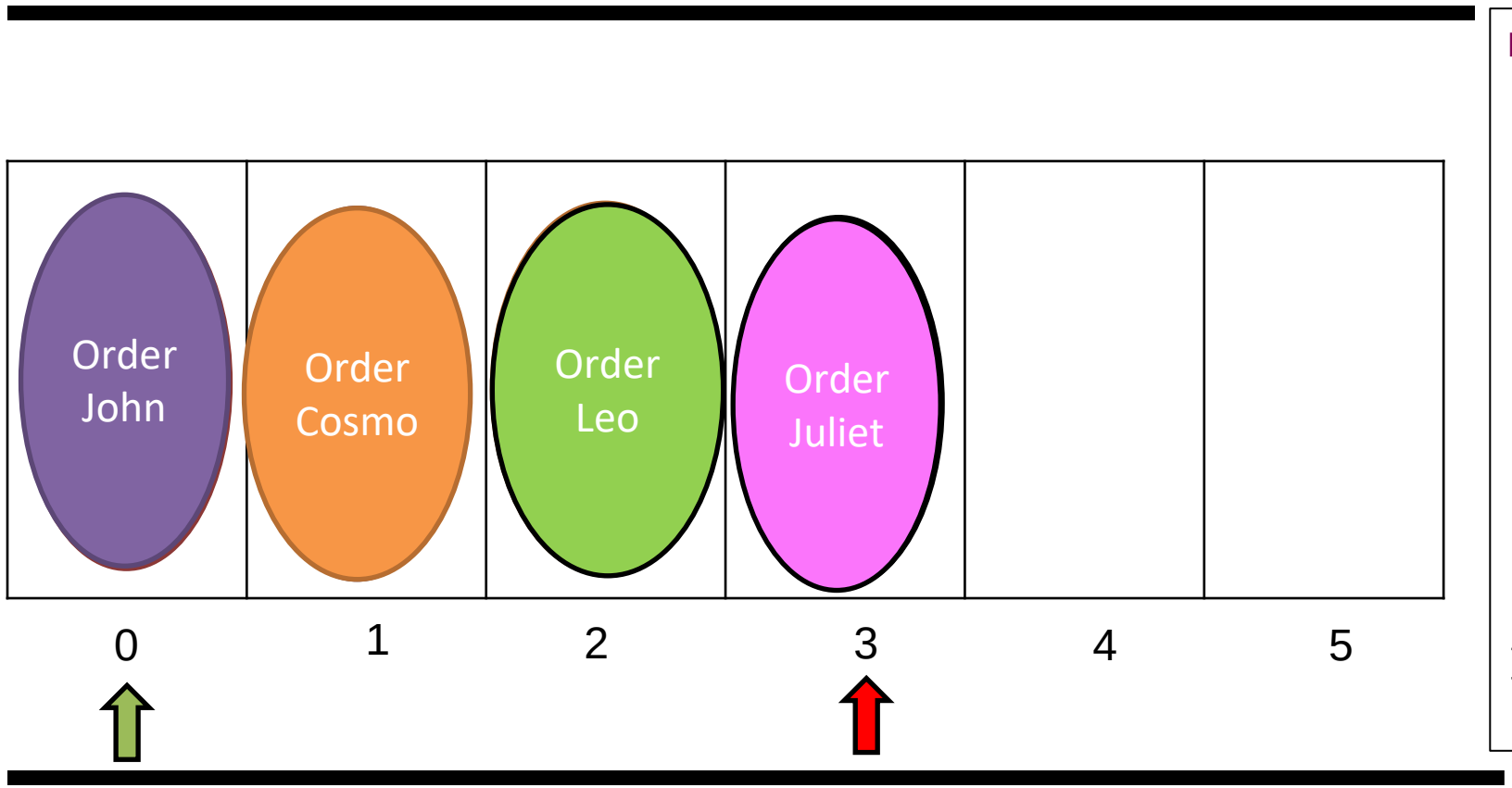
   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

`capacity = 6` `front = 0`

`size = 4` `rear = 3`

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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 }
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   }
   if(back < capacity) {
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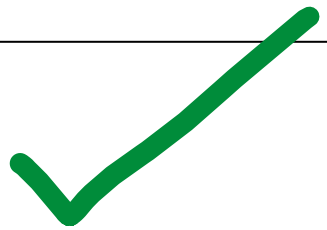
   }
   this.back--;
   this.size--;
 }
}
```

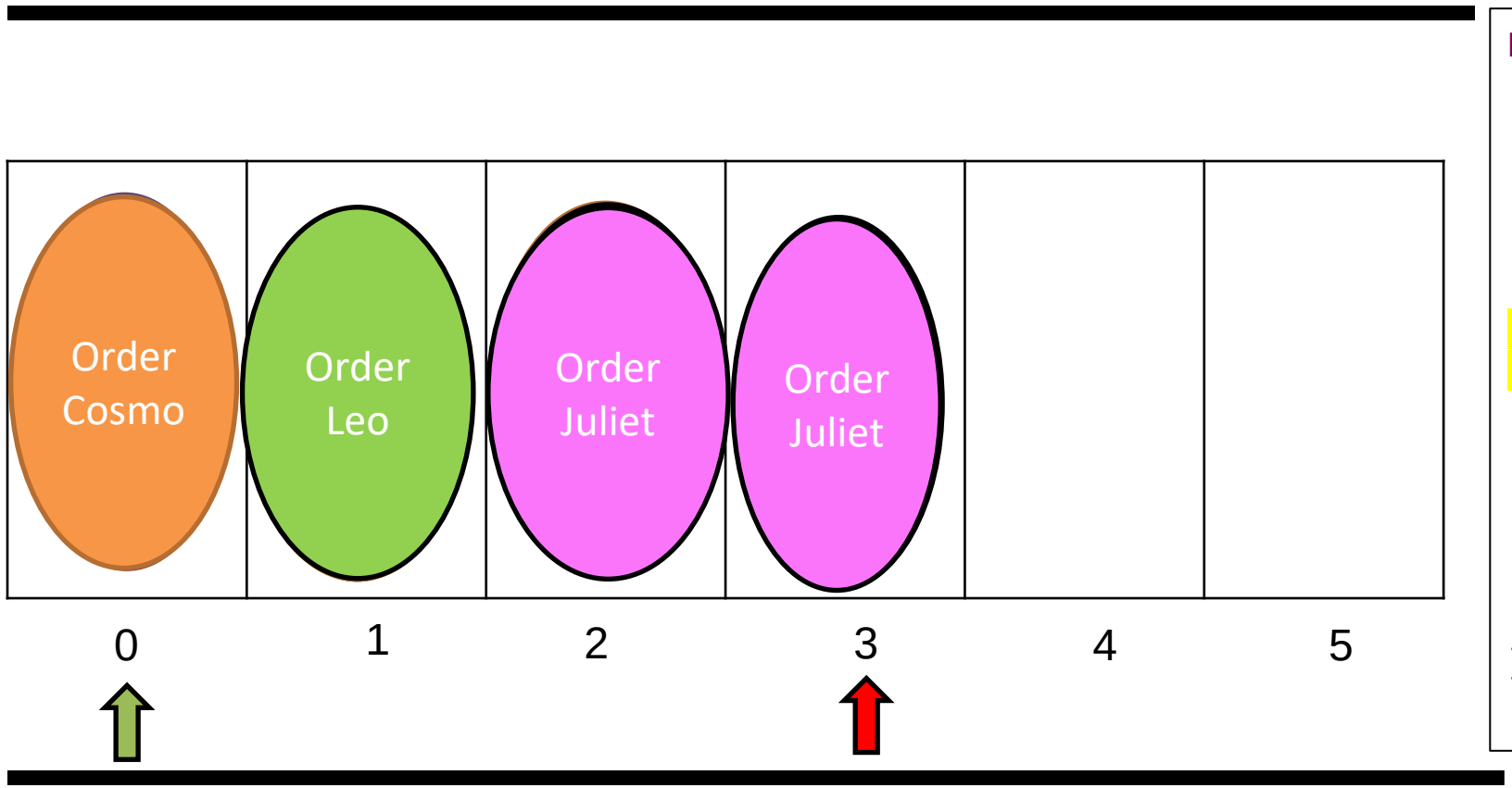


`capacity = 6` `front = 0`

`size = 4` `rear = 3`

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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`size = 4` `rear = 3`

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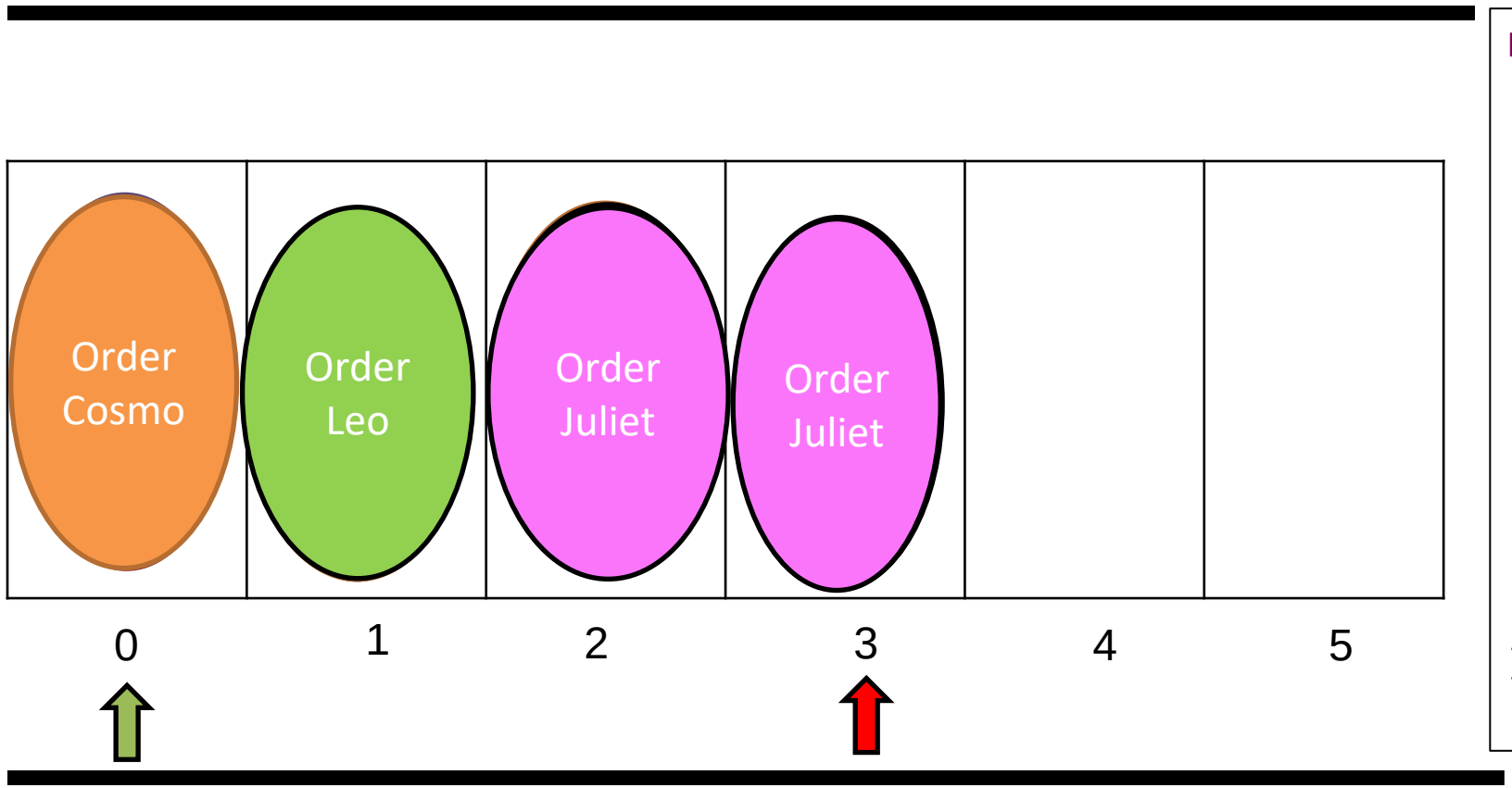


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 }
 else {
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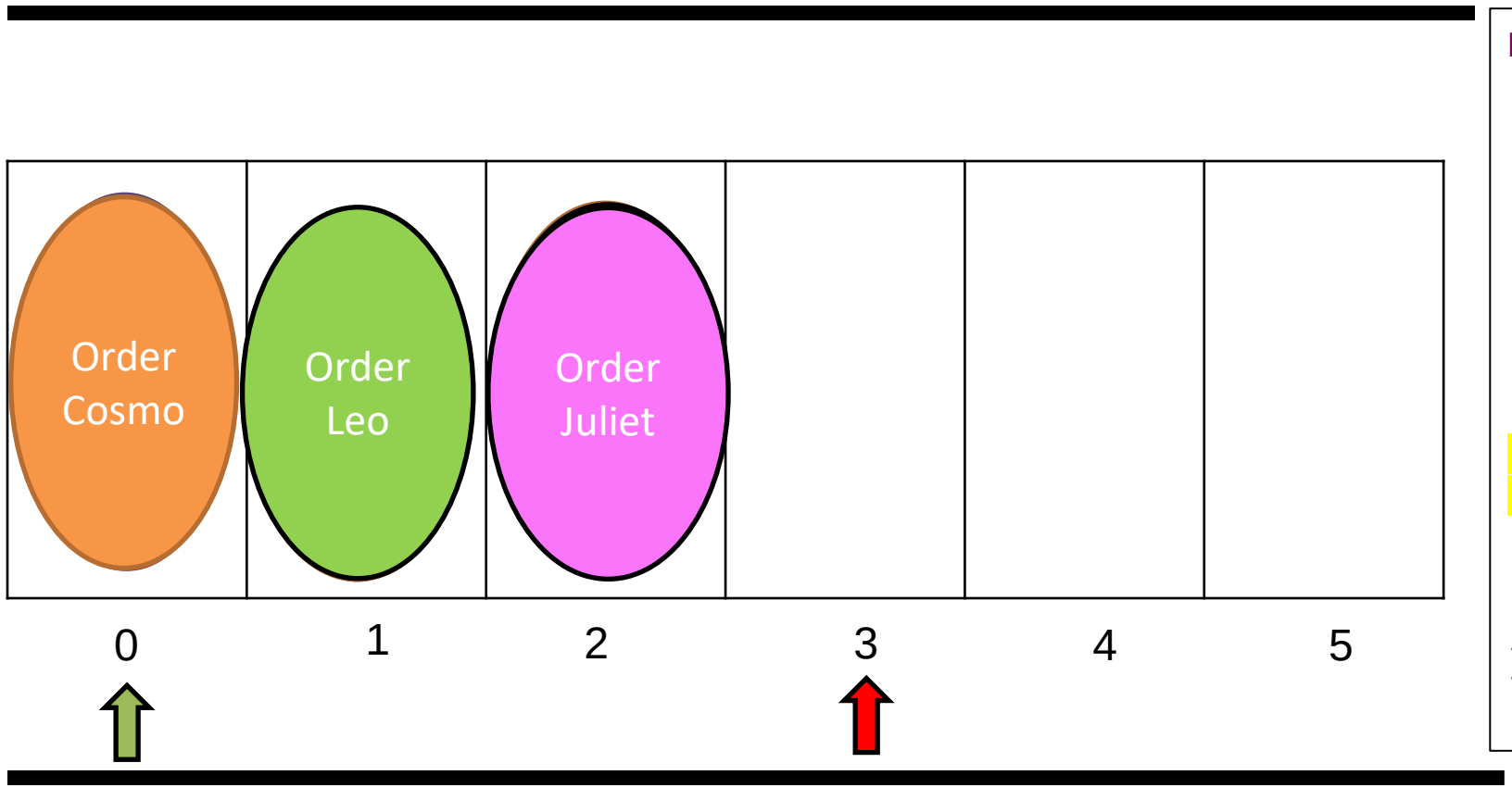
      this.orders[i] = this.orders[i+1];
   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

```
capacity = 6    front = 0
size = 4        rear = 3
```

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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 else {
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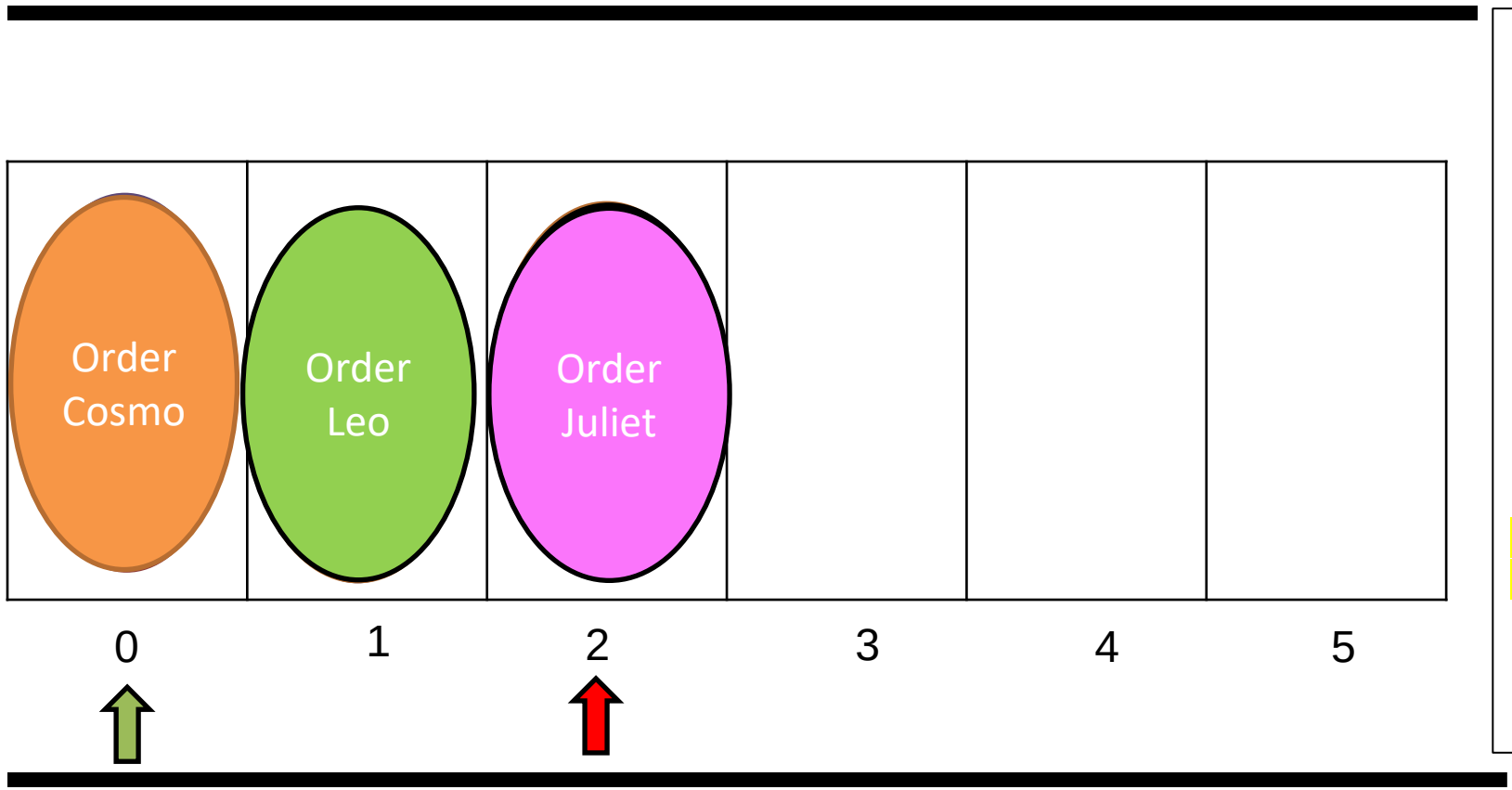
   }
   if(back < capacity) {
      this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

`capacity = 6` `front = 0`

`size = 4` `rear = 3`

Today, we will be implementing a Queue with an Array.

Suppose that we have a queue that can hold 6 elements

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 if(this.size == 0) {
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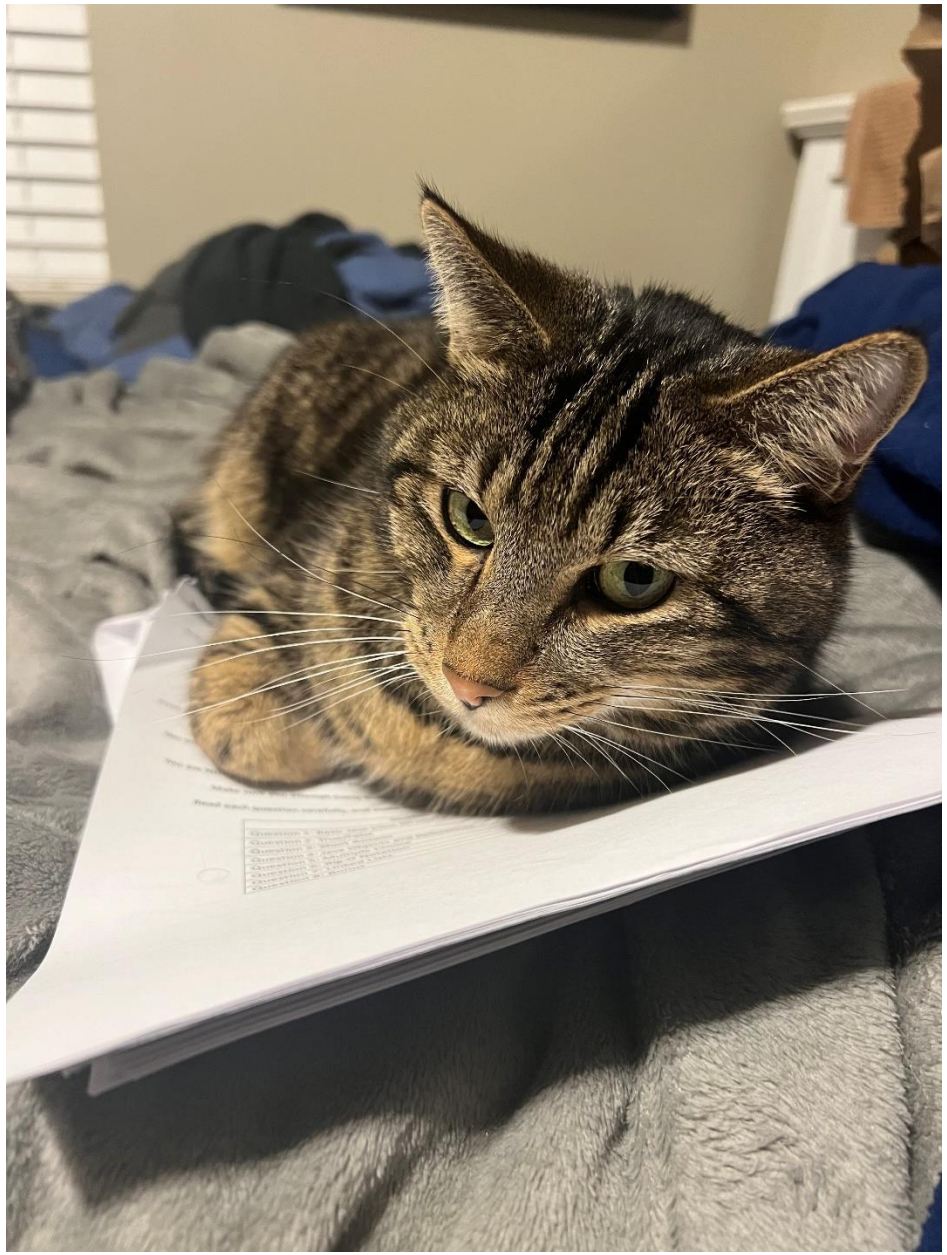
   return;
 }
 else {
   for(int i = 0; i < back-1; i++) {
      this.orders[i] = this.orders[i+1];
   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

```
capacity = 6    front = 0
size = 3        rear = 2
```



Runtime Analysis

```
public void enqueue(Order newOrder) {
   if(rear == capacity) {
      System.out.println("full...");
      return;
   }
   else {
      rear++;
      this.data[rear] = newOrder;
      this.size++;
   }
}
```

Runtime Analysis

```
public void enqueue(Order newOrder) {
   if(rear == capacity) { O(1)
      System.out.println("full..."); O(1)
      return; O(1)
   }
   else {
      rear++; O(1)
      this.data[rear] = newOrder; O(1)
      this.size++; O(1)
   }
}
```

Runtime Analysis

```
public void enqueue(Order newOrder) {
   if(rear == capacity) { O(1)
      System.out.println("full..."); O(1)
      return; O(1)
   }
   else {
      rear++; O(1)
      this.data[rear] = newOrder; O(1)
      this.size++; O(1)
   }
}
```

Total running time:

O(1)

```
public void dequeue() {
 if(this.size == 0) {
   System.out.println("empty...");
   return;
 }
 else {
   for(int i = 0; i < back-1; i++) {
      this.orders[i] = this.orders[i+1];
   }
   if(back < capacity) {
       this.orders[back] = null;
   }
   this.back--;
   this.size--;
 }
}
```

```
public void dequeue() {
 if(this.size == 0) {                                  O(1)
   System.out.println("empty...");                     O(1)
   return;                                             O(1)
 }
 else {
   for(int i = 0; i < back-1; i++) {                   O(N-1)
      this.orders[i] = this.orders[i+1];               O(1)
   }
   if(back < capacity) {                               O(1)
       this.orders[back] = null;                       O(1)
   }
   this.back--;                                        O(1)
   this.size--;                                        O(1)
 }
}
```

N = # elements in our queue

```
public void dequeue() {
 if(this.size == 0) {                    O(1)
   System.out.println("empty...");       O(1)
   return;                                O(1)
 }
 else {
   for(int i = 0; i < back-1; i++) {      O(N-1)
      this.orders[i] = this.orders[i+1];  O(1)
   }
   if(back < capacity) {                  O(1)
       this.orders[back] = null;          O(1)
   }
   this.back--;                           O(1)
   this.size--;                           O(1)
 }
}
```

N = # elements in our queue

Total running time:

O(N)

```
public void dequeue() {
 if(this.size == 0) {                    O(1)
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   return;                                O(1)
 }
 else {
   for(int i = 0; i < back-1; i++) {      O(N-1)
      this.orders[i] = this.orders[i+1];  O(1)
   }
   if(back < capacity) {                  O(1)
       this.orders[back] = null;          O(1)
   }
   this.back--;                           O(1)
   this.size--;                           O(1)
 }
}
```

Total running time:

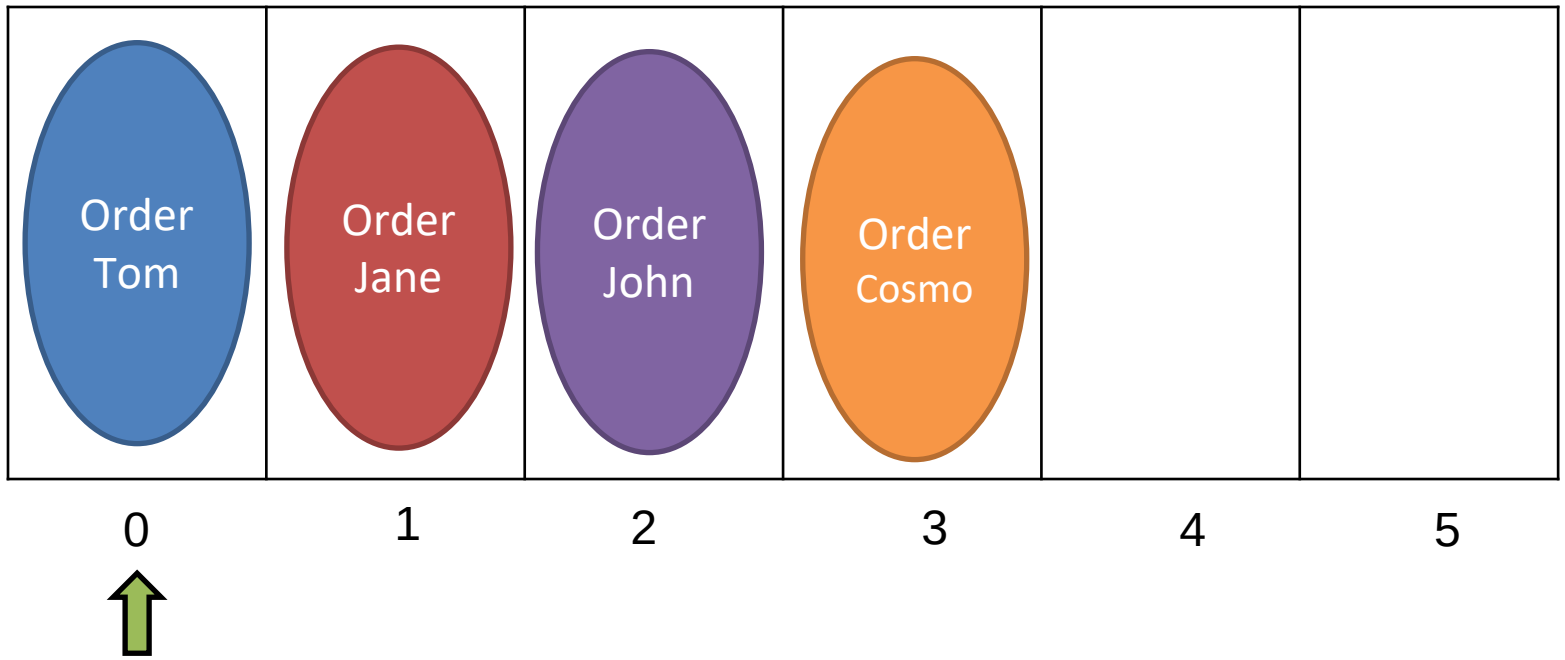
O(N)

This algorithm works fine, but the issue is that shifting data can be costly

(think about if this queue has 1000000 things in it→ we must shift 999999 elements!)

How to improve our queue?

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



We are going to make use of the **modulus** (%) operator !

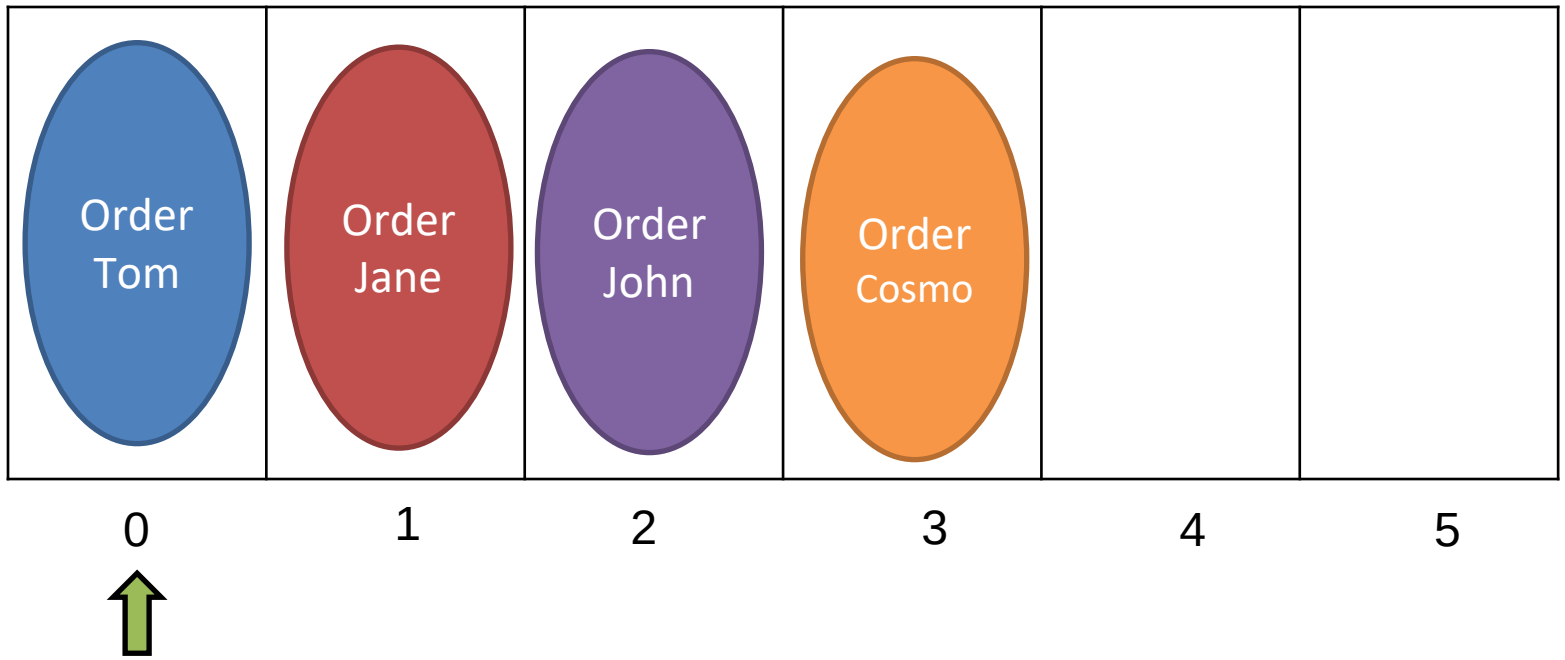
10 % 6 = 4

3 % 6 = 3

6 % 6 = 0

```
capacity = 6     front = 0
size = 4
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



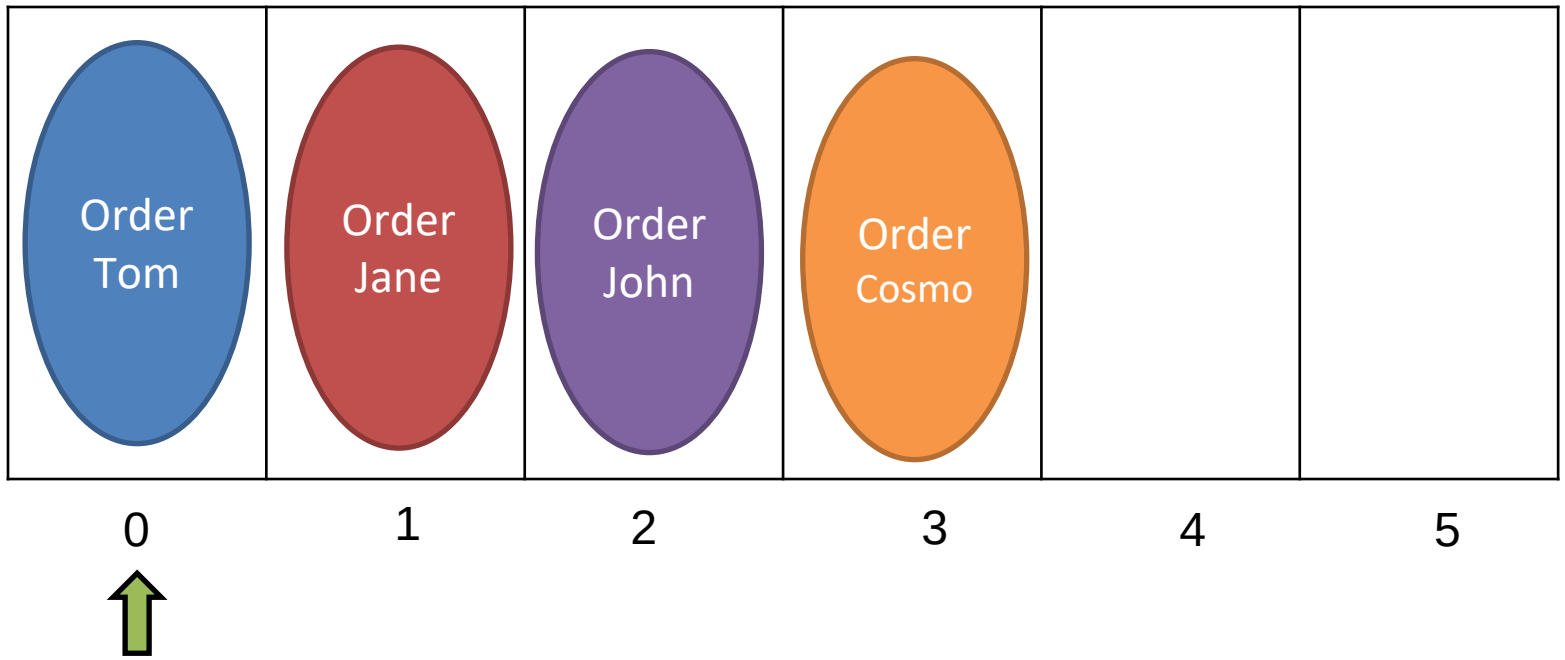

```
capacity = 6    front = 0
size = 4
```

Let's **enqueue**

Here is the formula for determining where to insert the new element

```
insert_spot = (front + size) % 6
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion




```
capacity = 6      front = 0
size = 4          insert_spot = 4
```

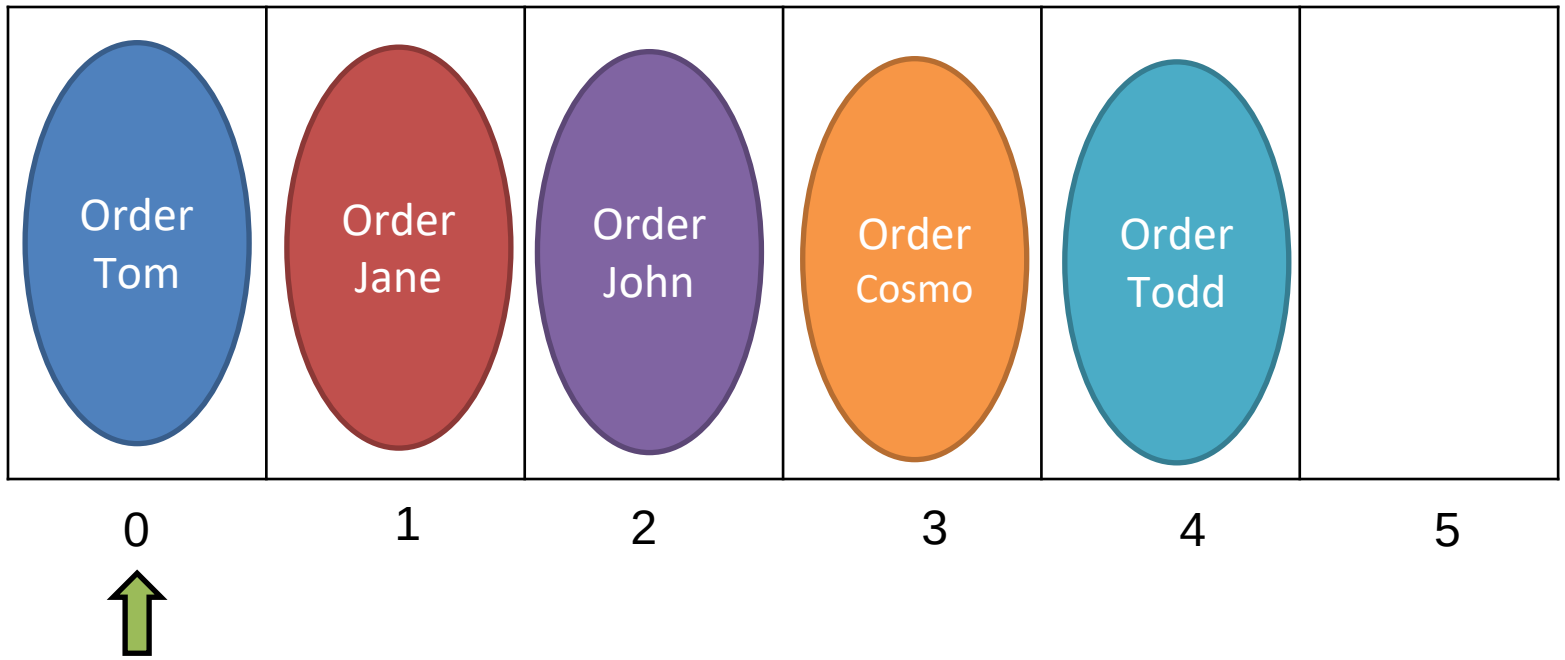
Let's **enqueue**

Here is the formula for determining where to insert the new element

```
insert_spot = (front + size) % 6
```

(0 + 4) % 6 = **Insert at spot 4**

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion




```
capacity = 6      front = 0
size = 4          insert_spot = 4
```

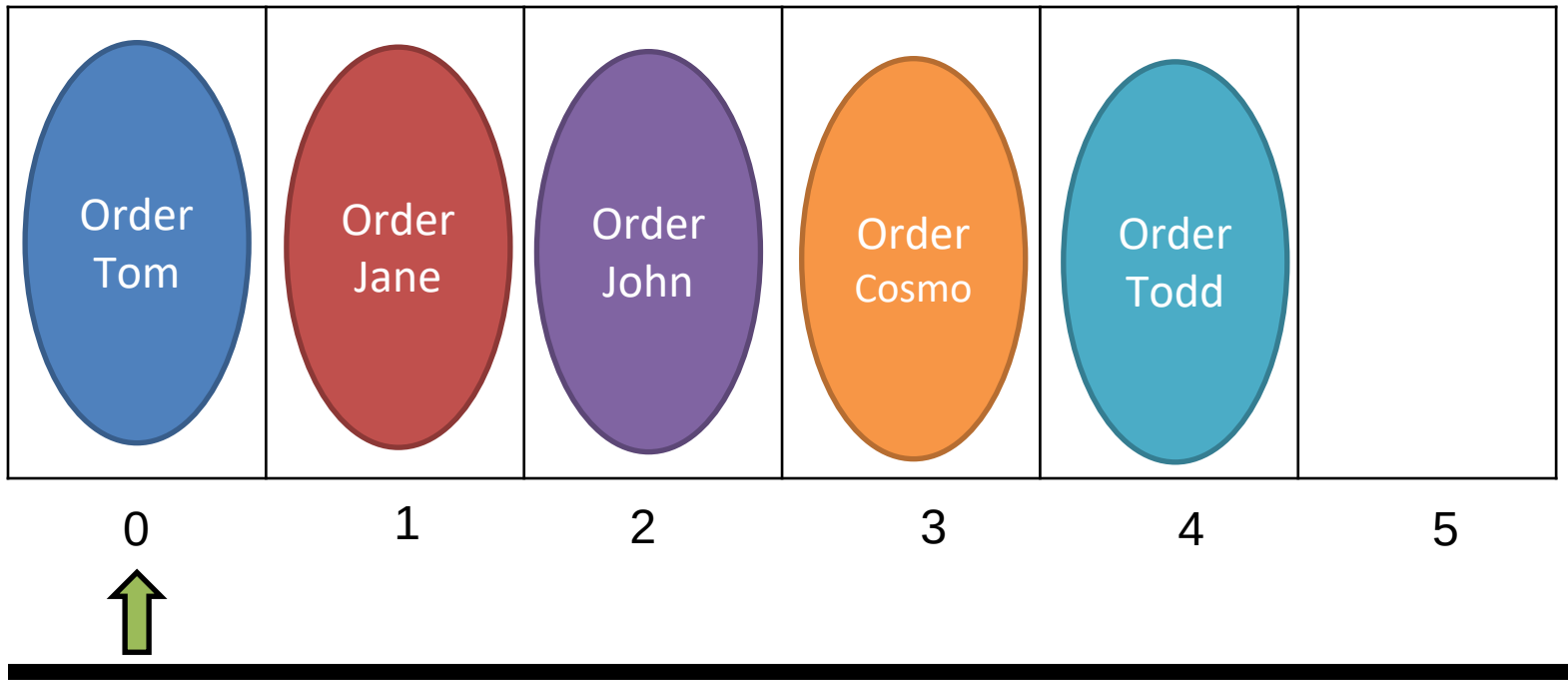
Let's **enqueue**

Here is the formula for determining where to insert the new element

```
insert_spot = (front + size) % 6
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion

Let's **dequeue**

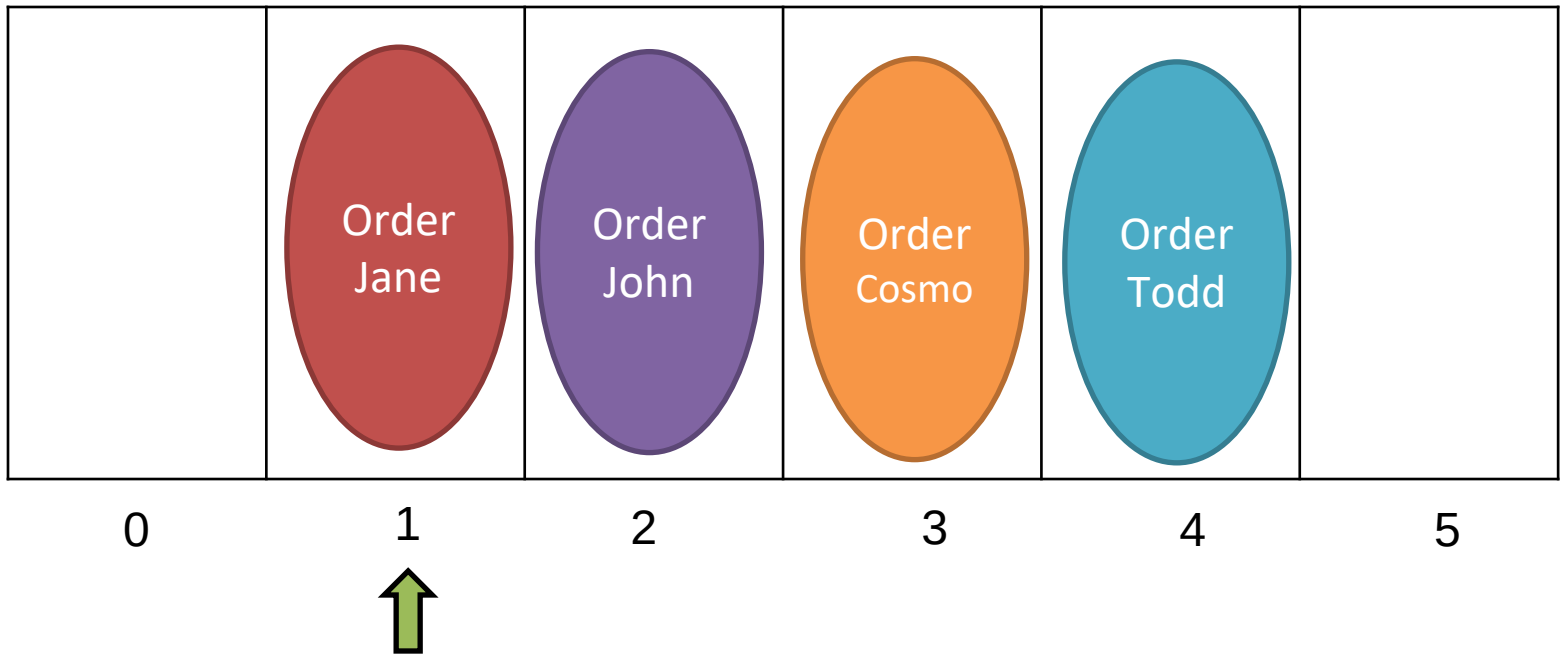



```
data[front] = null
```

```
capacity = 6      front = 0
size = 4          insert_spot = 4
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion

Let's **dequeue**




```
data[front] = null
```

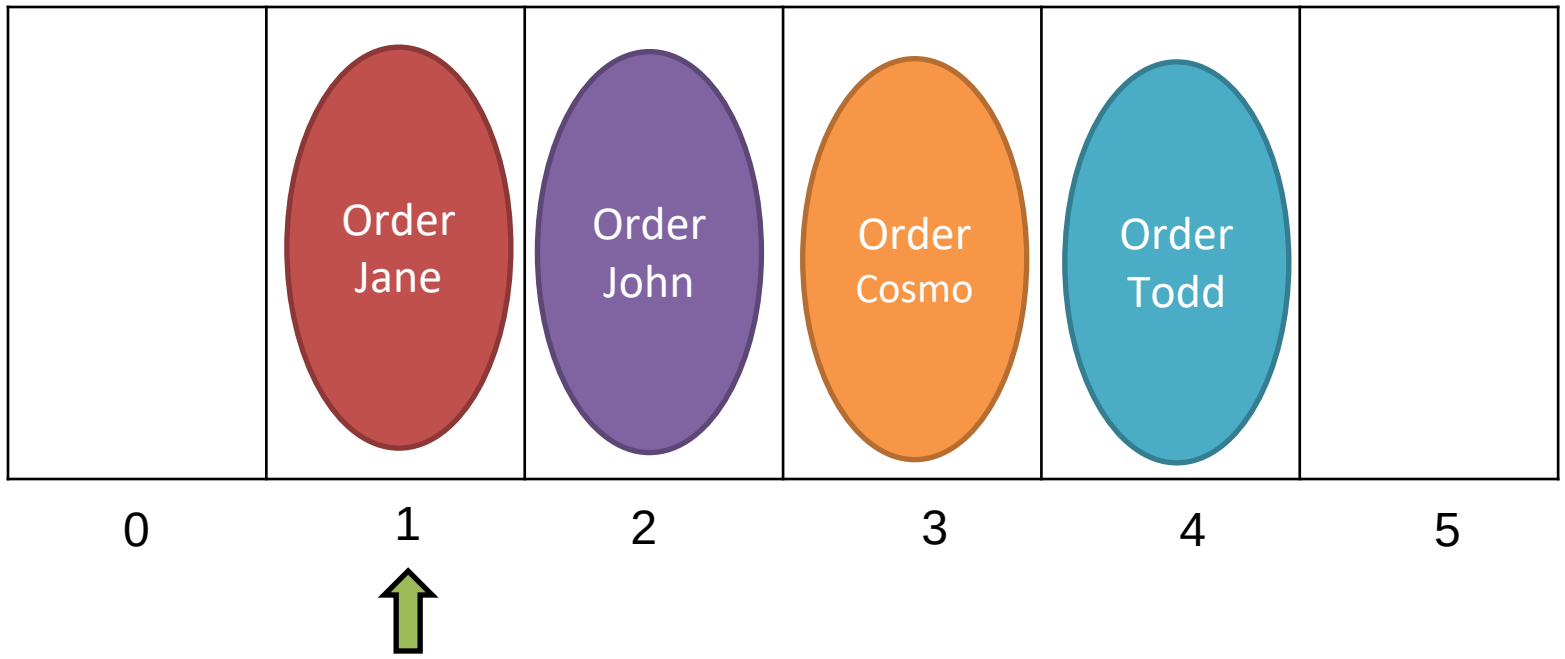
```
front = (front + 1) % 6
```

move the front pointer to the next element

= (0 + 1) % 6 = **1**

```
capacity = 6      front = 1
size = 4          insert_spot = 4
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **dequeue (again)**

```
data[front] = null
```

```
front = (front + 1) % 6
```

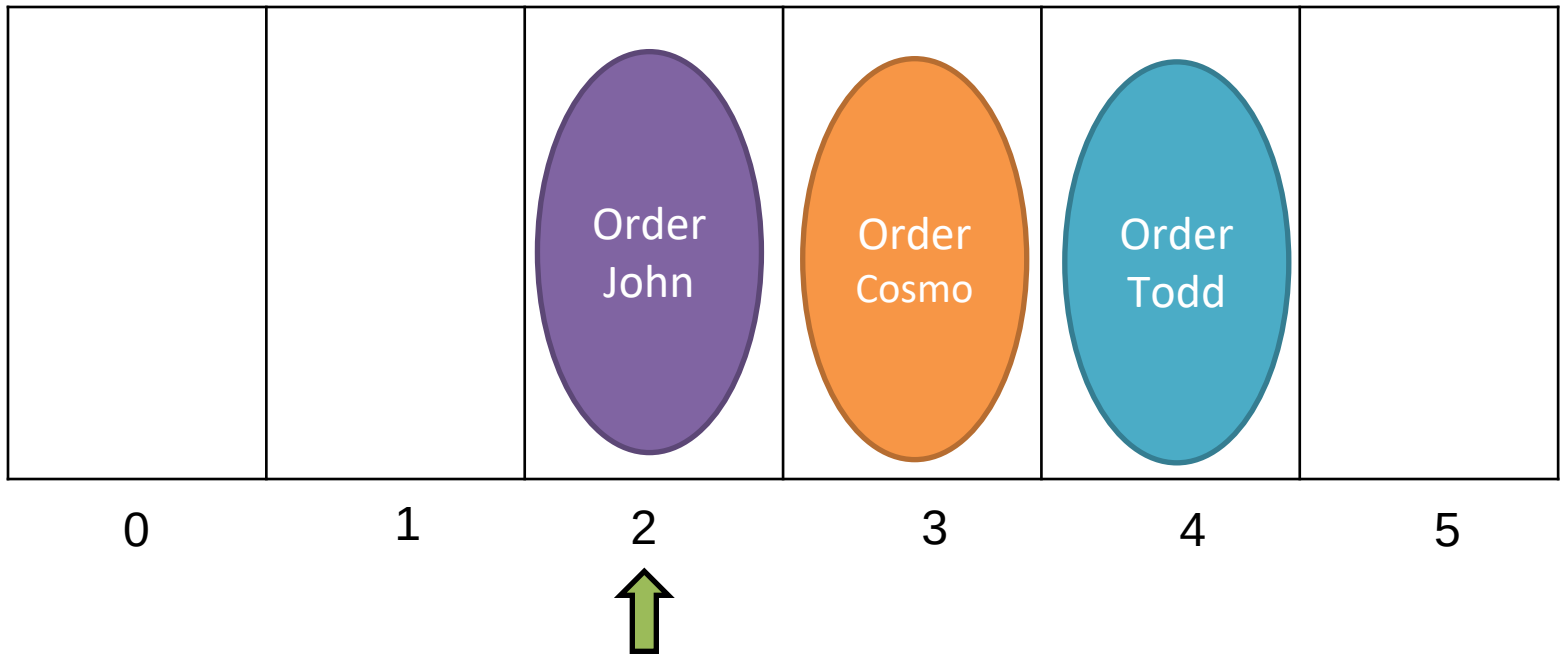
move the front pointer to the next element

= (0 + 1) % 6 = **1**

```
capacity = 6
size = 4
```

```
front = 1
insert_spot = 4
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **dequeue (again)**

```
data[front] = null
```

```
front = (front + 1) % 6
```

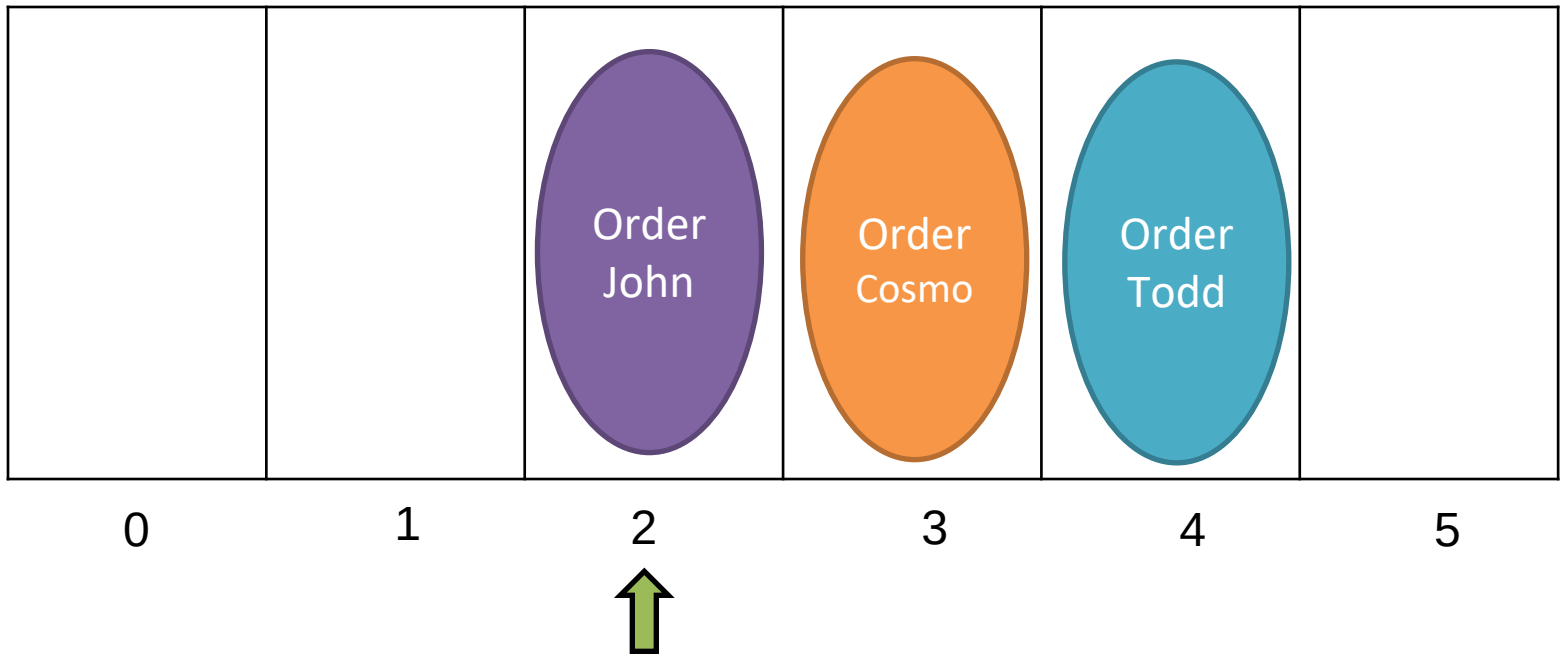
move the front pointer to the next element

= (1 + 1) % 6 = **2**

```
capacity = 6
size = 3
```

```
front = 2
insert_spot = 4
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **enqueue (again)**

```
insert_spot = (front + size) % 6
```

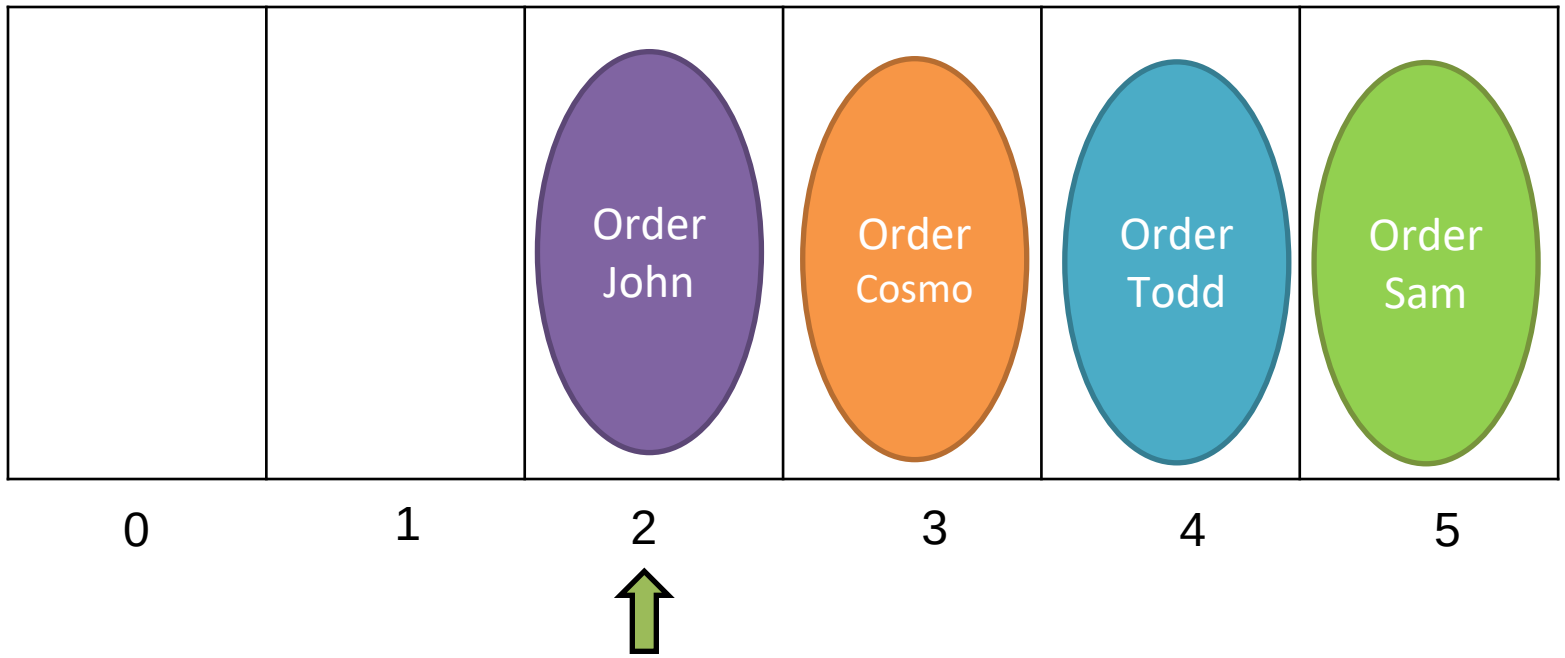
```
insert_spot = (2 + 3) % 6
```

5%6 = **5**


```
capacity = 6
size = 3
```

```
front = 2
insert_spot = 5
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **enqueue (again)**

```
insert_spot = (front + size) % 6
```

```
insert_spot = (2 + 3) % 6
```

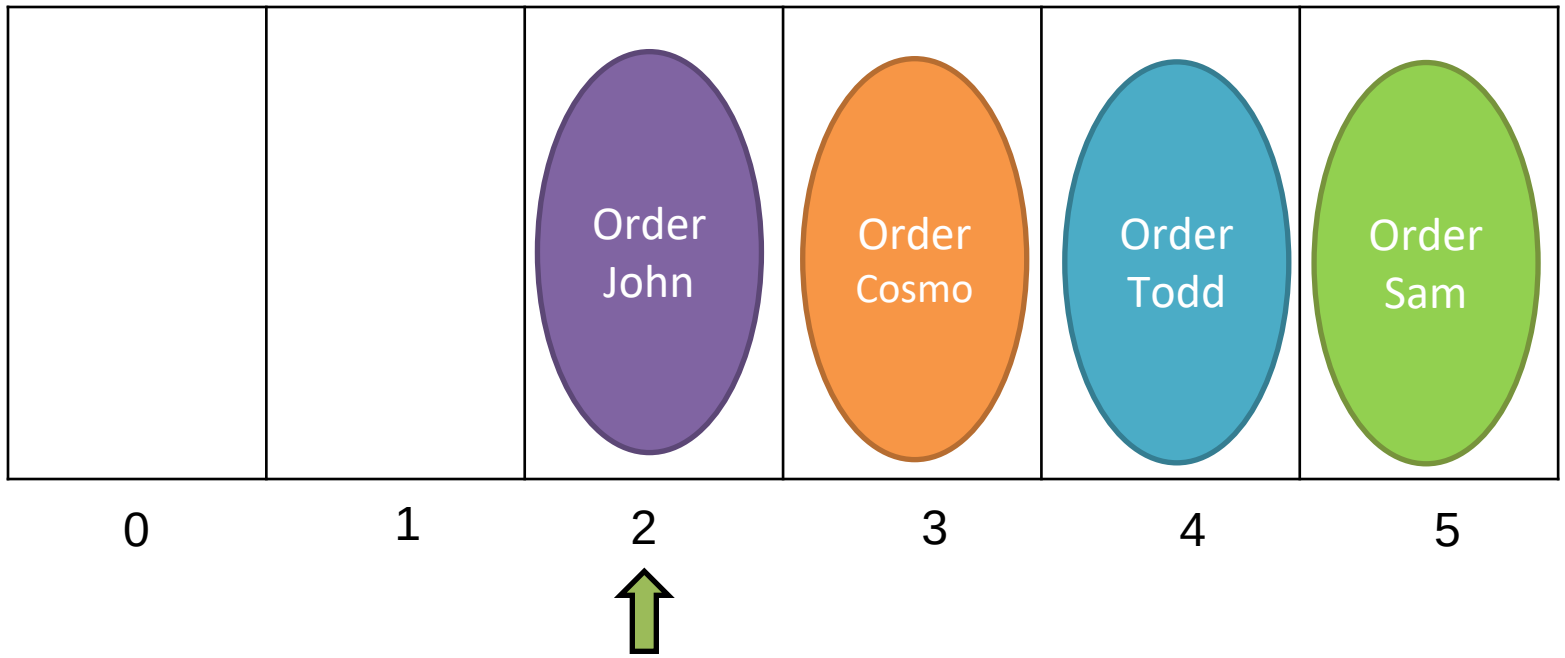
5%6 = **5**

```
capacity = 6
size = 4
```

```
front = 2
insert_spot = 5
```

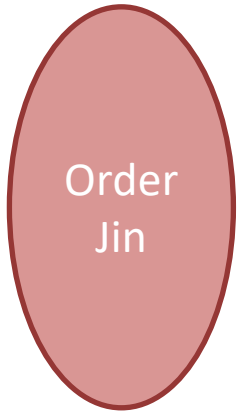
A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion

Let's **enqueue (<u>again</u>)**



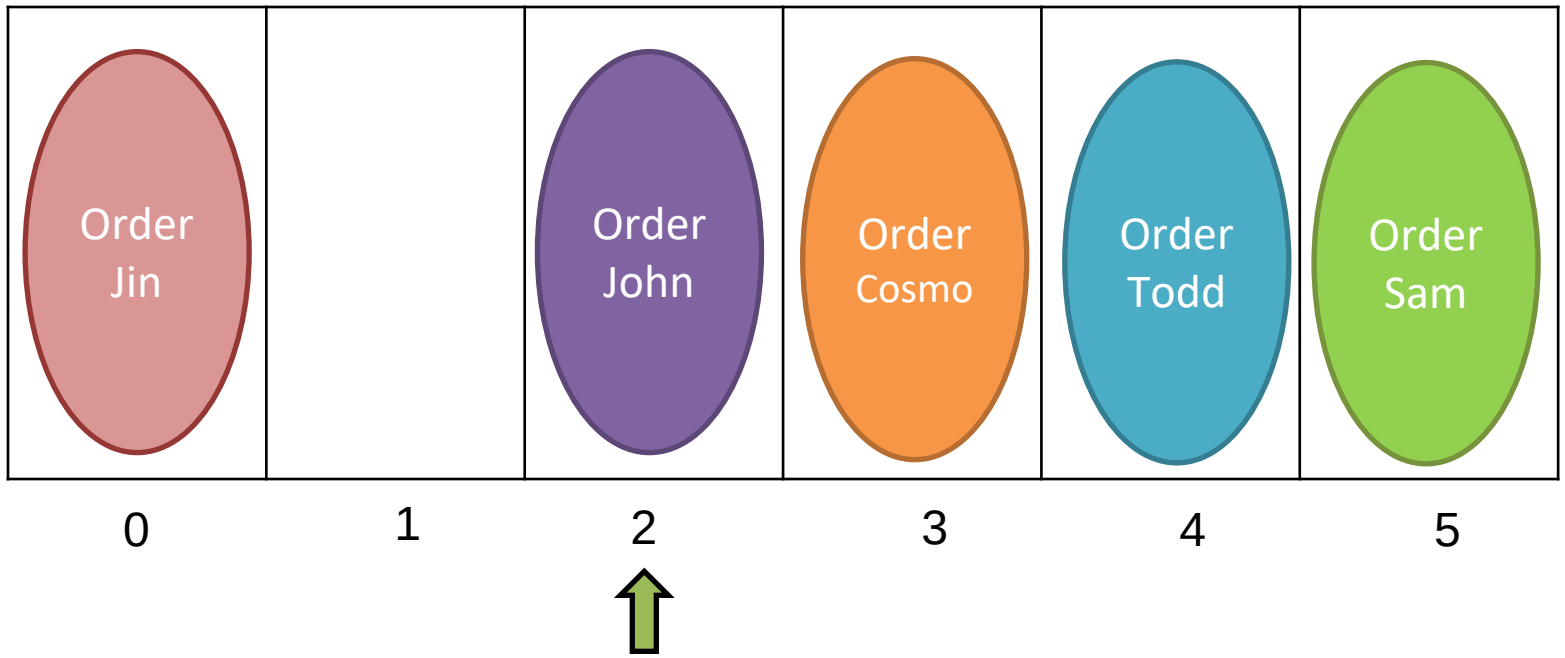

```
insert_spot = (front + size) % 6

(2 + 4) % 6  = 0
```




```
capacity = 6      front = 2
size = 4          insert_spot = 0
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **enqueue (again)**

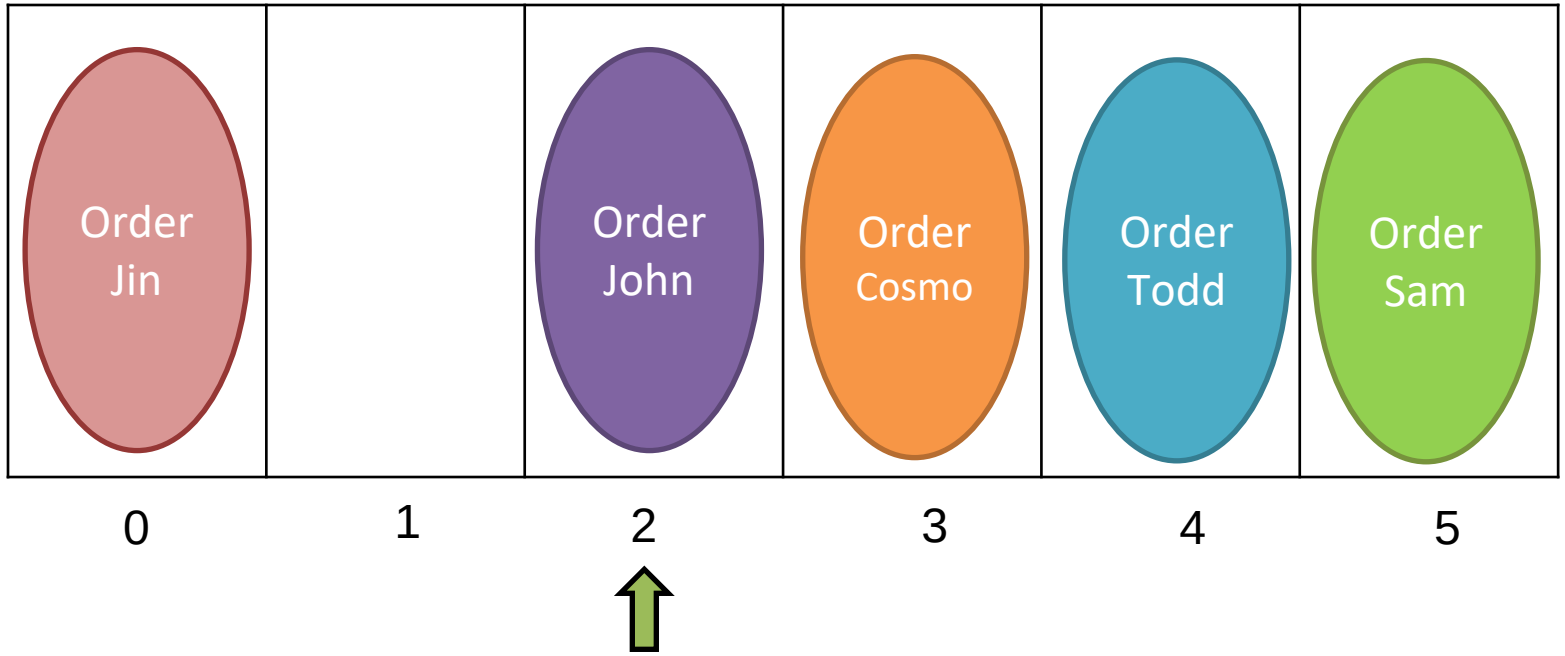
```
insert_spot = (front + size) % 6
```

```
(2 + 4) % 6  = 0
```

The modulus operator allows us to "**wrap around**" in our array!

```
capacity = 6      front = 2
size = 4          insert_spot = 0
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **dequqe (again)**

```
data[front] = null
```

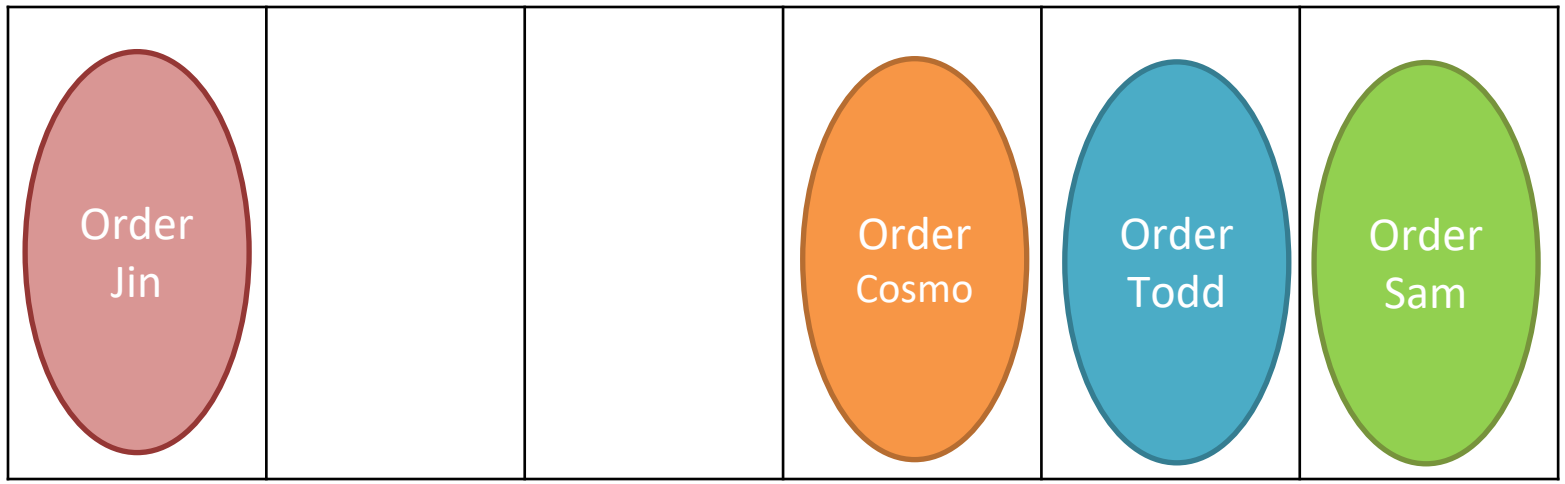
```
front = (front + 1) % 6
```

The modulus operator allows us to "**wrap around**" in our array!

```
capacity = 6
size = 4
```

```
front = 2
insert_spot = 0
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion




```
capacity = 6      front = 3
size = 4          insert_spot = 0
```

Let's **dequqe (<u>again</u>)**

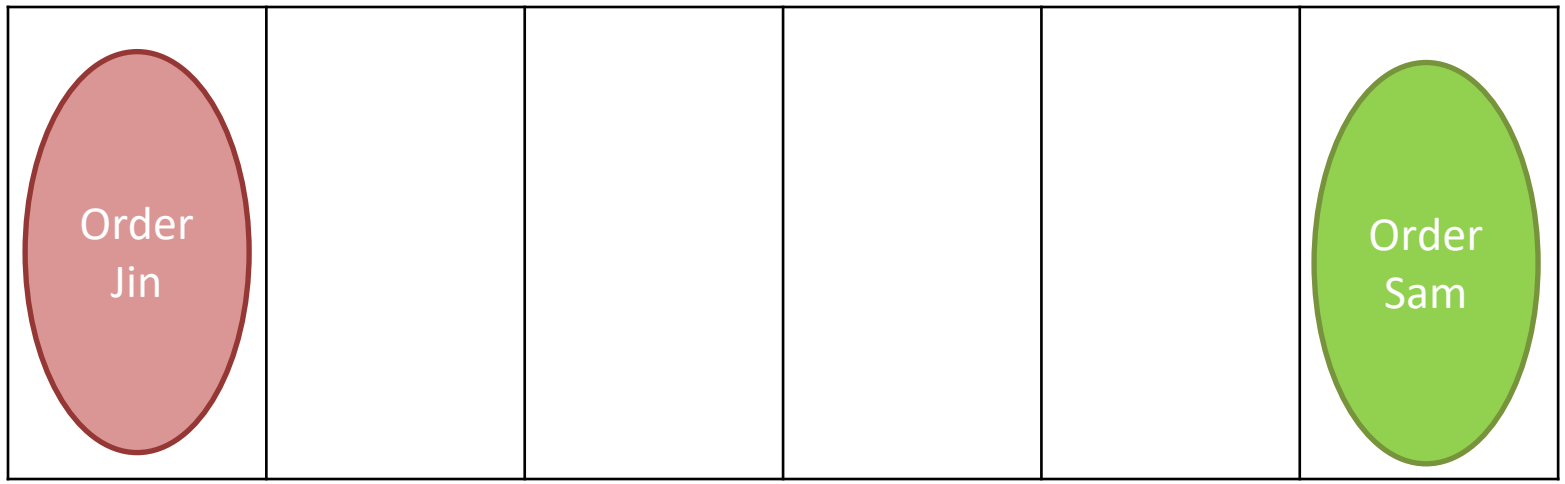
```
data[front] = null
```

```
front = (front + 1) % 6
```

(2+1) % 6 **= 3**

The modulus operator allows us to "**wrap around**" in our array!

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **dequqe (<u>again</u>)**

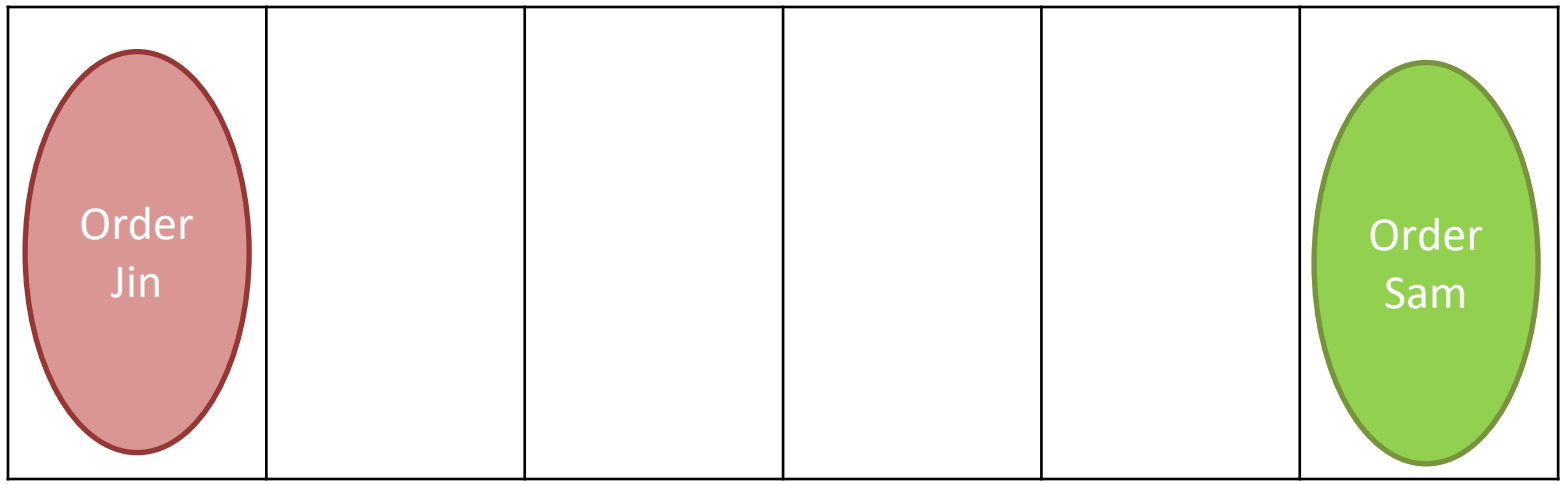
```
data[front] = null

front = (front + 1) % 6
```

```
capacity = 6
size = 2

front = 5
insert_spot = 0
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **dequqe (again)**

```
data[front] = null
```

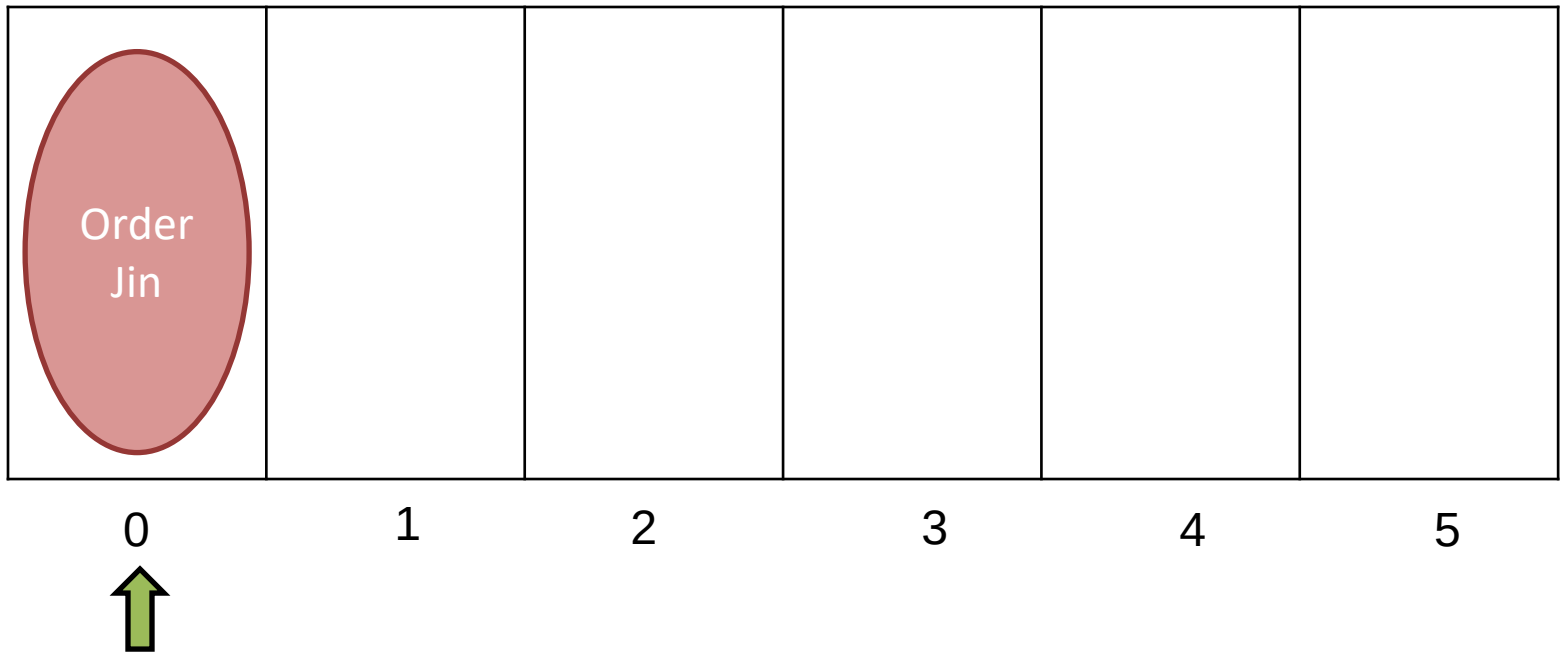
```
front = (front + 1) % 6
```

Front = (5 + 1) % 6 **= 0**

```
capacity = 6
size = 2
```

```
front = 5
insert_spot = 0
```

A **Queue** is a data structure that holds data, but operates in a First-in First-out (**FIFO**) fashion



Let's **dequqe (again)**

```
data[front] = null
```

```
front = (front + 1) % 6
```

Front = (5 + 1) % 6 **= 0**

```
capacity = 6
size = 1
```

```
front = 0
insert_spot = 0
```

```
public void enqueue(Order newOrder) {
    if(this.size == this.data.length) {
        System.out.println("Queue is full");
    }

    int insert_spot = (front + size) % (this.data.length);
    data[insert_spot] = newOrder;
    this.size++;

    System.out.println("Added "  +newOrder.getName() + " at index #" + insert_spot);
}
```

```
public void dequeue() {


    if(this.size == 0) {
        System.out.println("Queue is empty...");
        return;
    }
    else {

        Order o = this.data[front];
        this.data[front] = null;
        front = (front + 1) % this.data.length;
        this.size--;
        System.out.println(o.getName() + " order was removed ");
    }

}
```

Queue Runtime Analysis

```
public QueueLinkedList() {
        this.orders = new LinkedList<Order>();
        this.size = 0;
}
```

```
public QueueArray2() {
        this.orders = new Order[6];
        this.size = 0;
        this.front = 0;
        this.capacity = this.orders.length; //6
}
```

	Linked List	Array
Creation		
Enqueue		
Dequeue		
Peek		
Print Queue		

Queue Runtime Analysis

```
public QueueLinkedList() {
        this.orders = new LinkedList<Order>();
        this.size = 0;
}
```

O(1)

```
public QueueArray2() {
        this.orders = new Order[6];
        this.size = 0;
        this.front = 0;
        this.capacity = this.orders.length; //6
}
```

O(n), n = | array |

	Linked List	Array
Creation	O(1)	O(n)
Enqueue		
Dequeue		
Peek		
Print Queue		

Queue Runtime Analysis

```
public void enqueue(Order newOrder) {

        this.orders.addLast(newOrder);
        this.size++;

}
```

```
public void enqueue(Order newOrder) {

        if(this.size == this.capacity) {
                System.out.println("Error... queue is full");
                return;
        }

        int insert_spot = (front + size) % capacity;
        this.orders[insert_spot] = newOrder;

        this.size++;
        System.out.println("Added " + newOrder.getName() + " at index #" + insert_spot);
}
```

	Linked List	Array
Creation	O(1)	O(n)
Enqueue		
Dequeue		
Peek		
Print Queue		

Queue Runtime Analysis

```
public void enqueue(Order newOrder) {

        this.orders.addLast(newOrder);
        this.size++;

}
```

O(1)
O(1)
O(1)

```
public void enqueue(Order newOrder) {

        if(this.size == this.capacity) {
                System.out.println("Error... queue is full");
                return;
        }

        int insert_spot = (front + size) % capacity;
        this.orders[insert_spot] = newOrder;

        this.size++;
        System.out.println("Added " + newOrder.getName() + " at index #" + insert_spot);
}
```

O(1)
O(1)
O(1)
O(1)
O(1)

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue		
Peek		
Print Queue		

Queue Runtime Analysis

```
public Order dequeue() {
        if(this.size != 0) {
                Order removed = this.orders.removeFirst();
                System.out.println(removed.getName() + "'s order
                size--;
                return removed;
        }
        else {
                return null;
        }
}
```

```
public void dequeue() {

        if(this.size == 0) {
                System.out.println("Error... queue is empty");
                return;
        }
        else {
                Order o = this.orders[front];
                this.orders[front] = null;
                front = (front + 1) % capacity;
                this.size--;
                System.out.println(o.getName() + "'s order was removed");

        }

}
```

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue		
Peek		
Print Queue		

Queue Runtime Analysis

```
public Order dequeue() {
        if(this.size != 0) {
                Order removed = this.orders.removeFirst();
                System.out.println(removed.getName() + "'s order
                size--;
                return removed;
        }
        else {
                return null;
        }
}
```

O(1)

O(1)

```
public void dequeue() {

        if(this.size == 0) {
                System.out.println("Error... queue is empty");
                return;
        }
        else {
                Order o = this.orders[front];
                this.orders[front] = null;
                front = (front + 1) % capacity;
                this.size--;
                System.out.println(o.getName() + "'s order was removed");

        }

}
```

O(1)

O(1)

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue	O(1)	O(1)
Peek		
Print Queue		

Queue Runtime Analysis

```
return this.orders.getFirst()
```

```
return this.orders[front]
```

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue	O(1)	O(1)
Peek		
Print Queue		

Queue Runtime Analysis

```
return this.orders.getFirst()
```
O(1)

```
return this.orders[front]
```
O(1)

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue	O(1)	O(1)
Peek	O(1)	O(1)
Print Queue		

Queue Runtime Analysis

```
public void printQueue() {
        int counter = 1;
        for(Order each_order: this.orders) {
                each_order.printOrder(counter);
                counter++;
        }
}
```

```
public void printQueue() {

        int start = front;
        int counter = 1;
        int n = 0;
        while(n != this.size) {
                System.out.println(counter + ". " + this.orders[start].getName());
                start = (start + 1) % capacity;
                counter++;
                n++;
        }


}
```

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue	O(1)	O(1)
Peek	O(1)	O(1)
Print Queue		

Queue Runtime Analysis

```
public void printQueue() {
        int counter = 1;
        for(Order each_order: this.orders) {
            each_order.printOrder(counter);
            counter++;
        }
}
```

O(1) O(n) O(1) O(1)

n = # of elements in queue

```
public void printQueue() {

        int start = front;
        int counter = 1;
        int n = 0;
        while(n != this.size) {
                System.out.println(counter + ". " + this.orders[start].getName());
                start = (start + 1) % capacity;
                counter++;
                n++;
        }


}
```

O(1) O(1) O(1) O(n) O(1)

n = # of elements in queue

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue	O(1)	O(1)
Peek	O(1)	O(1)
Print Queue	O(n)	O(n)

Takeaway: Adding and removing elements from a **queue** runs in constant time (`O(1)`)

(FIFO)

Takeaway: Adding and removing elements from a **stack** runs in constant time (`O(1)`)

(LIFO)

Queue Runtime Analysis

	Linked List	Array
Creation	O(1)	O(n)
Enqueue	O(1)	O(1)
Dequeue	O(1)	O(1)
Peek	O(1)	O(1)
Print Queue	O(n)	O(n)

Stack Runtime Analysis

	w/ Array	w/ Linked List
Creation	O(n)	O(1)
Push()	O(1)	O(1)
Pop()	O(1)	O(1)
peek()	O(1)	O(1)
Print()	O(n)	O(n)