Prepared by Julian García, based on material by
David Albrecht and María García de la Banda

Lecture 22
Queues
(Array Implementation)

FIT 1008
Introduction to Computer Science

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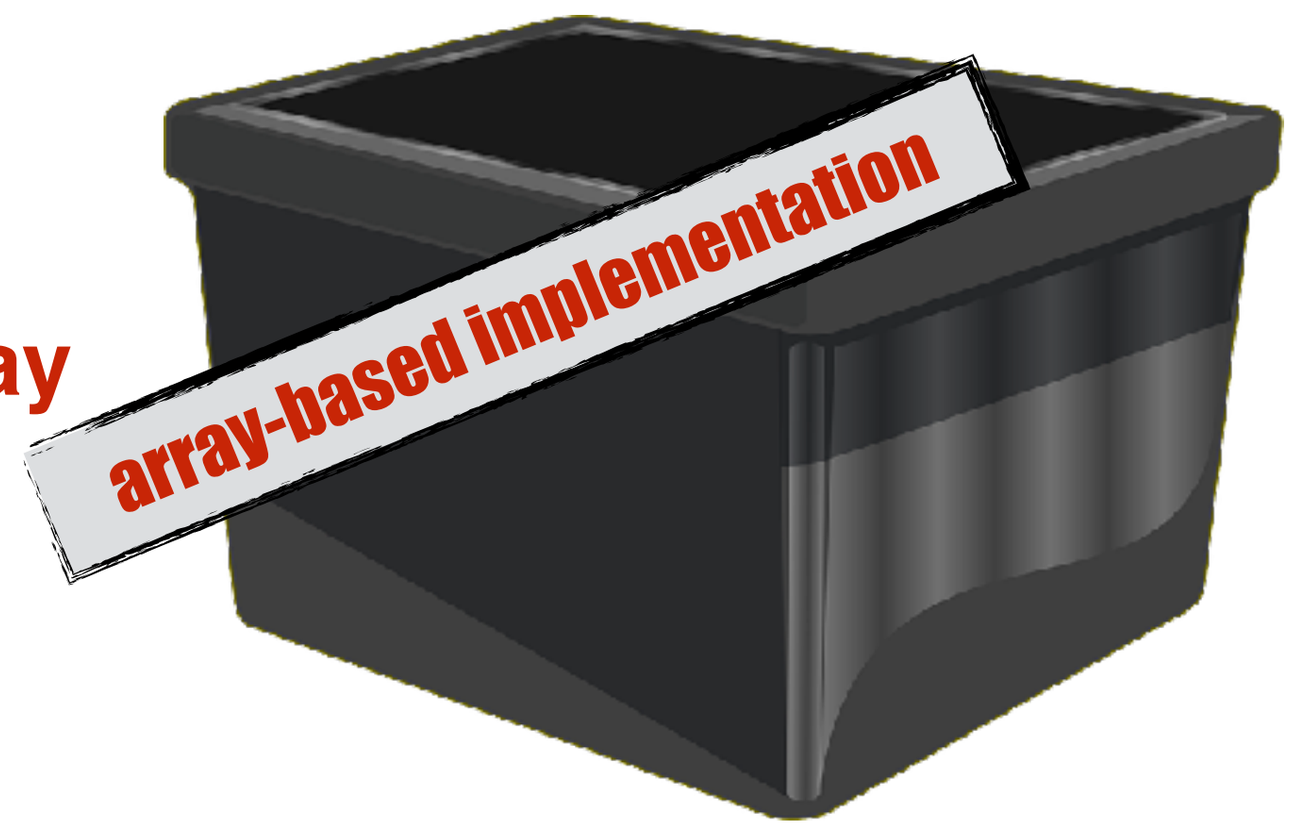
Container ADTs

- **Stores** and removes items **independent of contents.**
- **Examples** include:
  - List ADT ☑
  - Stack ADT ☑
  - Queue ADT. ← **Today**
- Core **operations**:
  - ➡ add item
  - ➡ remove item



“Form an orderly queue to the left..”

FIFO

- **FIFO** (First In First Out): The first element to arrive, is the first to be processed
- Data: The first element to be **added**, is the first to be deleted (or **served**)
- Access to any other element is unnecessary (and thus not allowed)

Queue Data Type

- Follows the **FIFO model**

- Its operations (interface) are:
  - **Create** the queue (Queue)
  - Add an item to the back (**append**)
  - Take an item off the front (**serve**)
  - Is the queue **empty**?
  - Is the queue **full**?
  - Empty the queue (**reset**)

Remember: you can only access the element at the front of the queue (first item inserted that is still in)

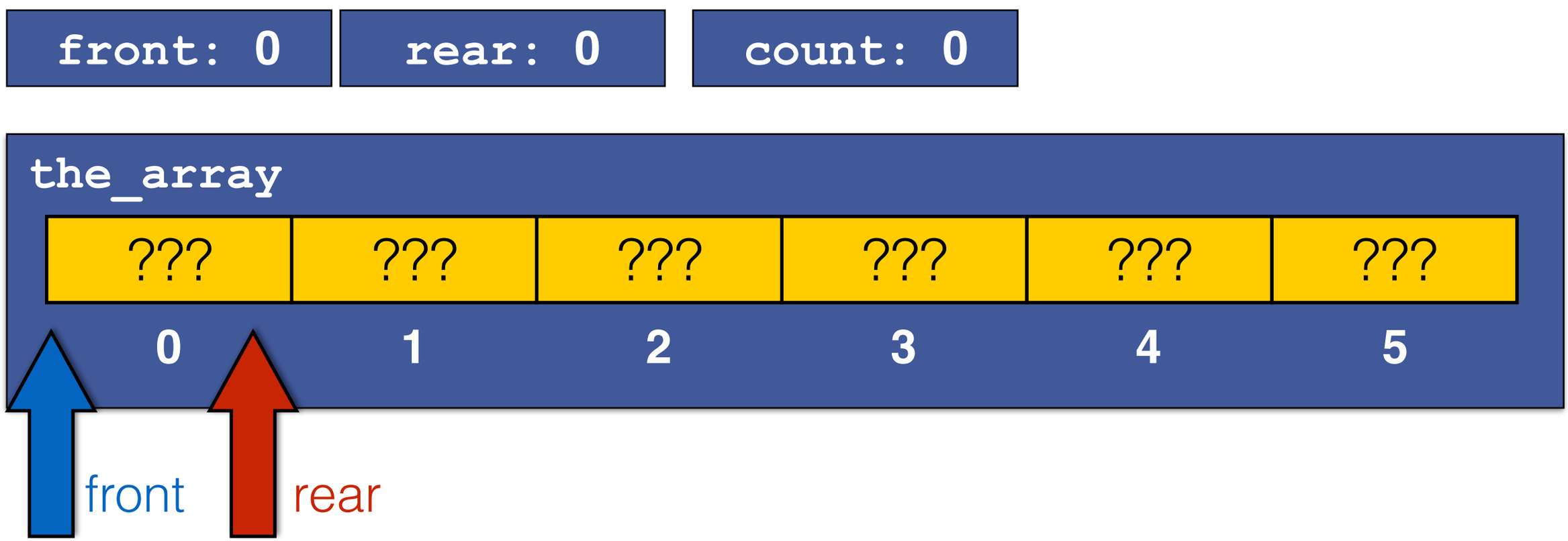
Possible implementation: linear queue

- We need to: **add items** at the **<u>rear</u>**. **take** items from the **<u>front.</u>**

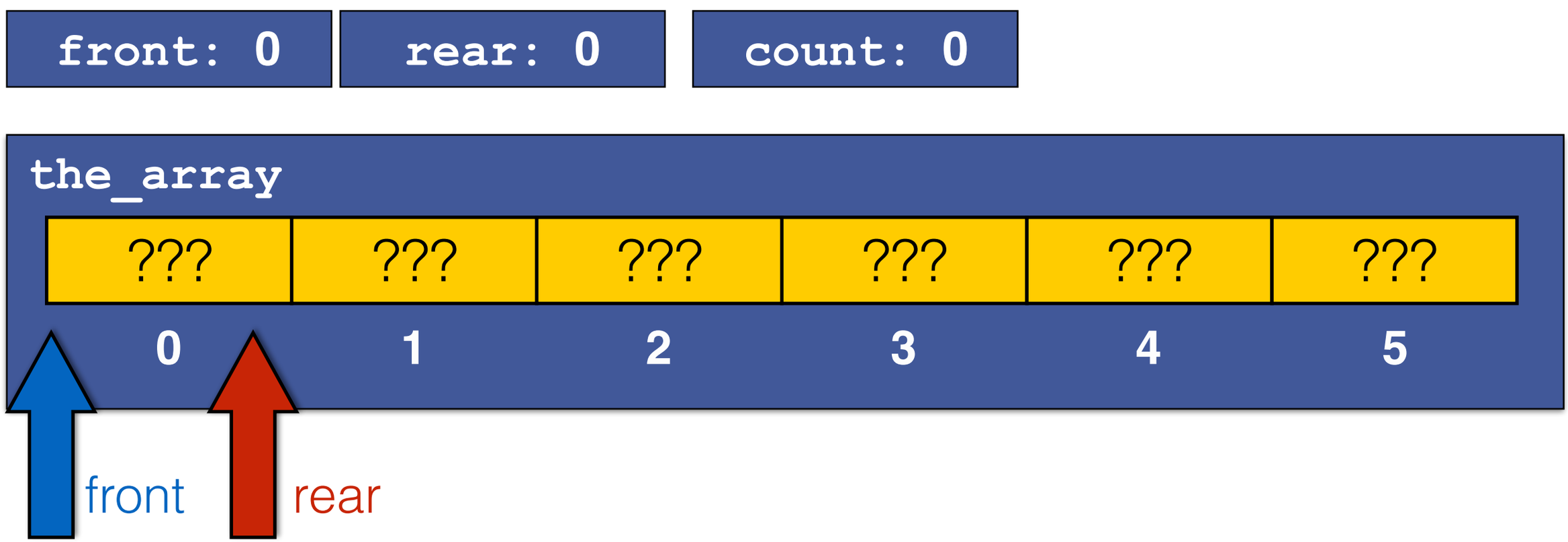
  A single marker is not going to be enough.

- Lets try implementing queues using:
  - An **array** to store the items in the order they arrive.
  - An **integer** marking the <u>front</u> of the queue. Refers to the first element to be served.
  - An **integer** marking the <u>rear</u> of the queue. Refers to the first empty slot at the rear.
  - An integer **count** keeping track of the number of items.

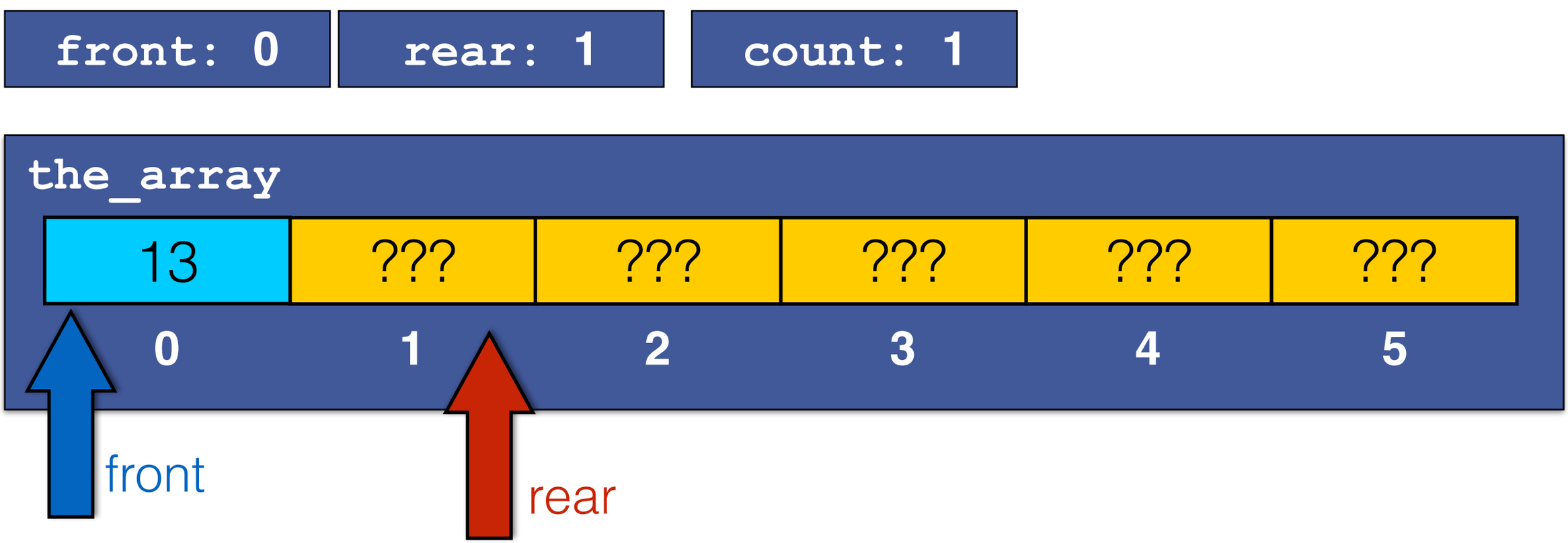
- **Invariant**: <u>valid data</u> appears in `front` … `rear-1` positions


front: 0
rear: 0
count: 0
the_array
???
???
???
???
???
???
0
1
2
3
4
5
front
rear

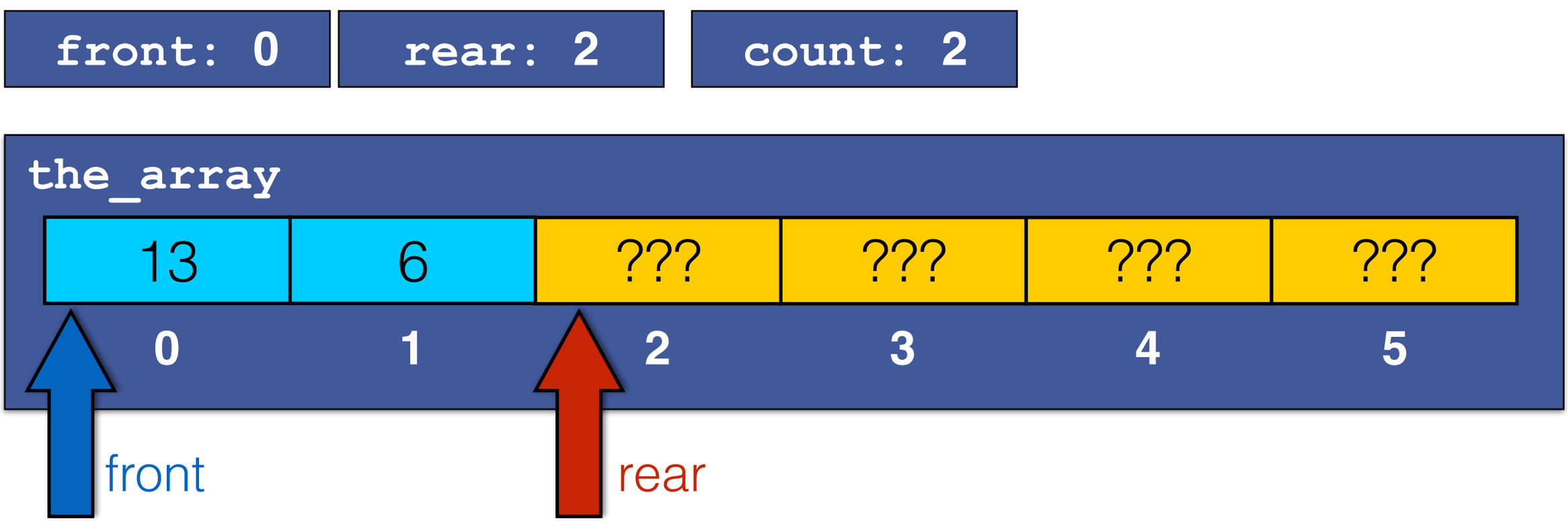
- Create a new queue: no items



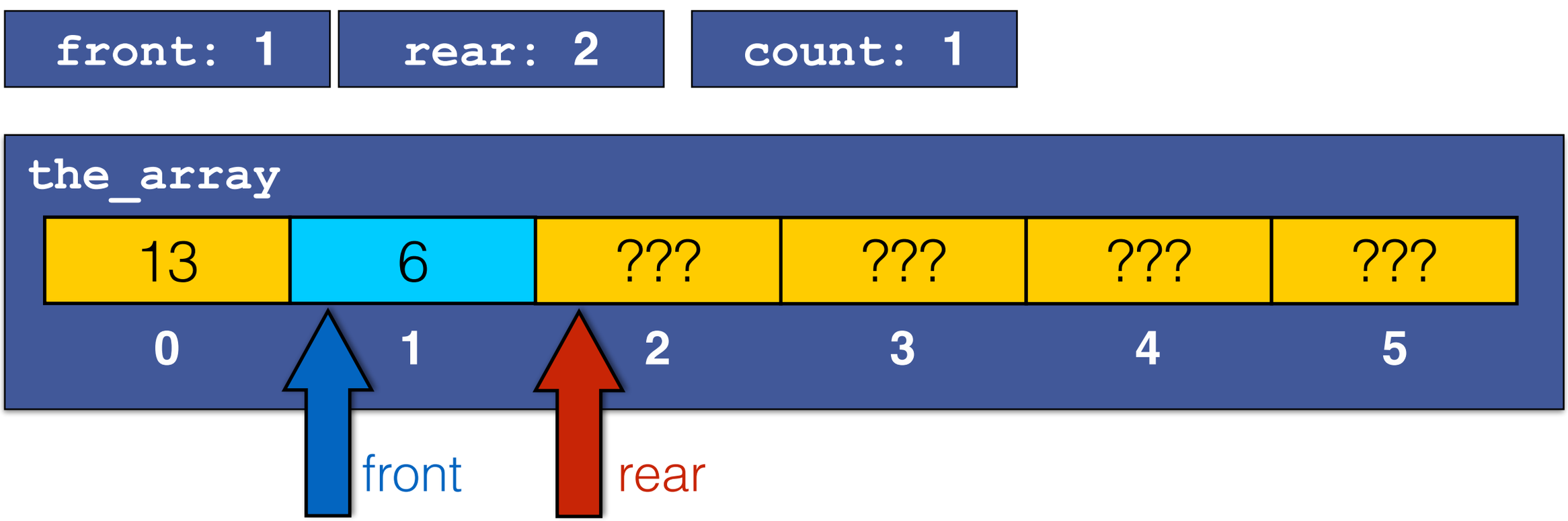
- Create a new queue: no items
- Append item 13



- Create a new queue: no items
- Append item 13
- Append item 6



- Create a new queue: no items
- Append item 13
- Append item 6
- Serve item 13



Creating a Linear Queue

```
class Queue:
    def __init__(self, size):
        assert size > 0, "Size should be positive"
        self.the_array = size*[None]
        self.count = 0
        self.rear = 0
        self.front = 0
```

Creating a Linear Queue

```
class Queue:
    def __init__(self, size):
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```

Creating a Linear Queue

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        self.count = 0
        self.rear = 0
        self.front = 0
```

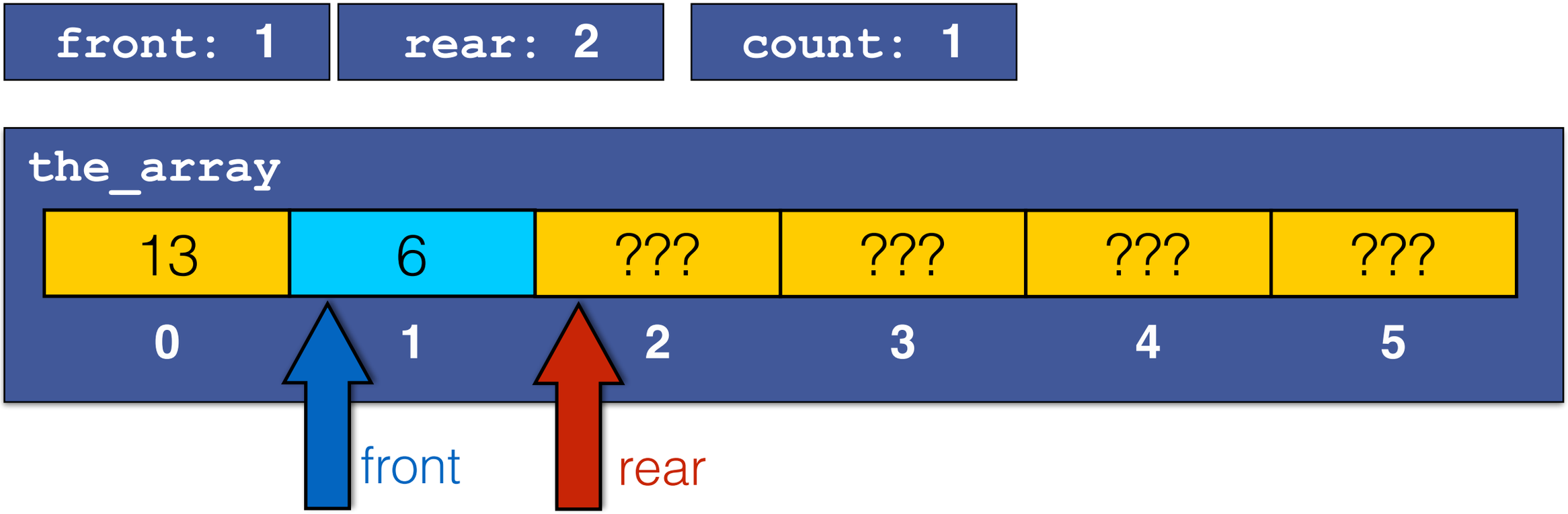
Instance variables

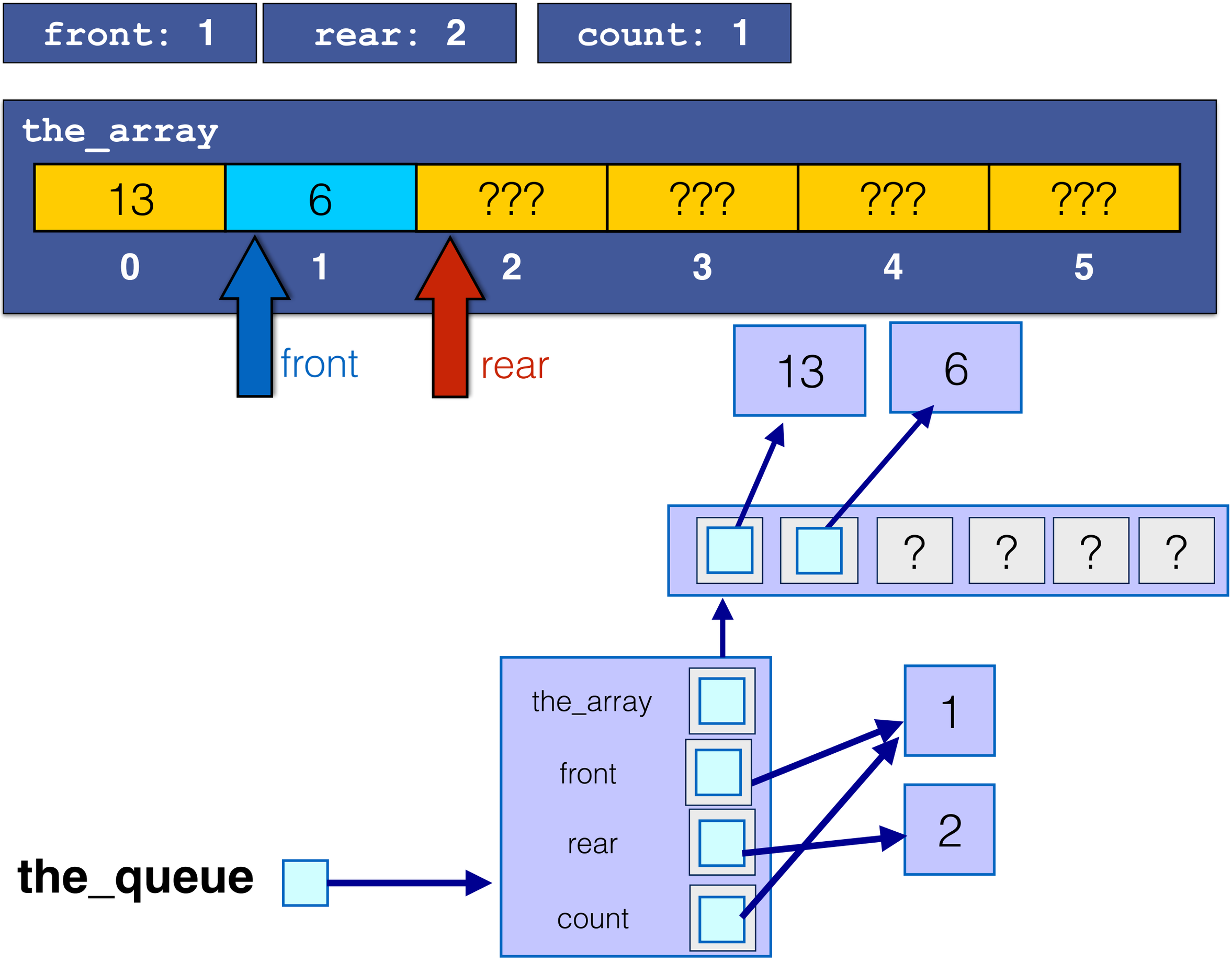
Creating a Linear Queue

```
class Queue:
    def __init__(self, size):
        assert size > 0, "Size should be positive"
        self.the_array = size*[None]
        self.count = 0
        self.rear = 0
        self.front = 0
```

Instance variables

Complexity is O(N)


front: 1
rear: 2
count: 1
the_array
13
6
???
???
???
???
0
1
2
3
4
5
front
rear


front: 1
rear: 2
count: 1
the_array
13
6
???
???
???
???
0
1
2
3
4
5
front
rear
13
6
?
?
?
?
the_array
front
rear
count
1
2
the_queue

Simple methods

```
def is_full(self):
    return self.rear >= len(self.the_array)

def is_empty(self):
    return self.count == 0

def reset(self):
    self.front = 0
    self.rear = 0
    self.count = 0
```

Simple methods

```
def is_full(self):
    return self.rear >= len(self.the_array)

def is_empty(self):
    return self.count == 0

def reset(self):
    self.front = 0
    self.rear = 0
    self.count = 0
```

Complexity is O(1)
for all of these methods.

Implementing Append

```
def append(self, new_item):
```

Implementing Append

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
```

Implementing Append

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
```

Implementing Append

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
```

Implementing Append

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
    self.count += 1
```

Implementing Append

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
    self.count += 1
```

Complexity is O(1)

Implementing Serve

```
def serve(self):
```

Implementing Serve

```
def serve(self):
    assert not self.is_empty(), "Queue is empty"
```

Implementing Serve

```
def serve(self):
    assert not self.is_empty(), "Queue is empty"
    item = self.the_array[self.front]
```

Implementing Serve

```
def serve(self):
    assert not self.is_empty(), "Queue is empty"
    item = self.the_array[self.front]
    self.front +=1
```

Implementing Serve

```
def serve(self):
    assert not self.is_empty(), "Queue is empty"
    item = self.the_array[self.front]
    self.front +=1
    self.count -=1
```

Implementing Serve

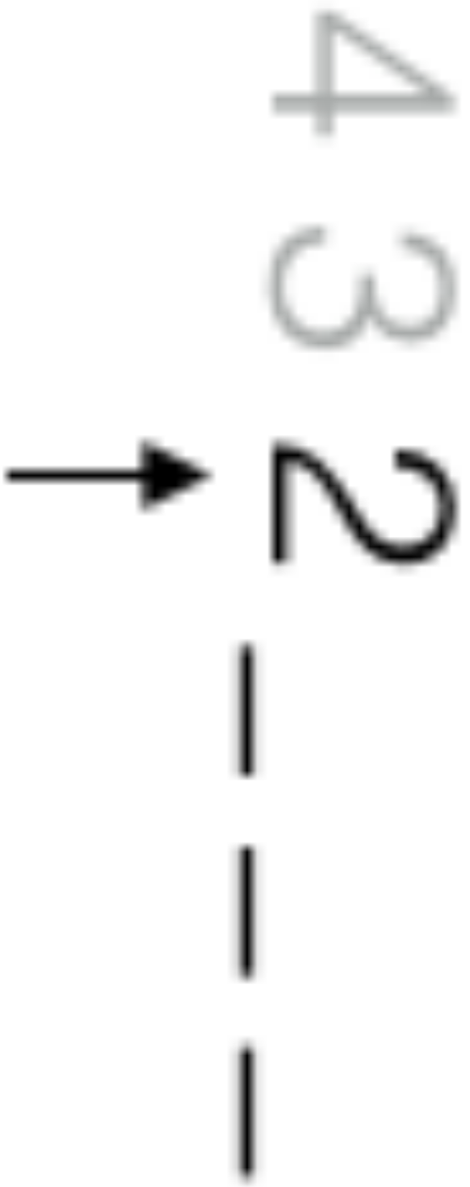
```
def serve(self):
    assert not self.is_empty(), "Queue is empty"
    item = self.the_array[self.front]
    self.front +=1
    self.count -=1
    return item
```

Implementing Serve

```
def serve(self):
    assert not self.is_empty(), "Queue is empty"
    item = self.the_array[self.front]
    self.front +=1
    self.count -=1
    return item
```

Complexity is O(1)

```python
class Queue:
    def __init__(self, size):
        assert size > 0, "Size should be positive"
        self.the_array = size*[None]
        self.count = 0
        self.rear = 0
        self.front = 0

    def is_full(self):
        return self.rear >= len(self.the_array)

    def is_empty(self):
        return self.count == 0

    def reset(self):
        self.front = 0
        self.rear = 0
        self.count = 0

    def append(self, new_item):
        assert not self.is_full(), "Queue is full"
        self.the_array[self.rear] = new_item
        self.rear += 1
        self.count += 1

    def serve(self):
        assert not self.is_empty(), "Queue is empty"
        item = self.the_array[self.front]
        self.front +=1
        self.count -=1
        return item
```


2
3
4

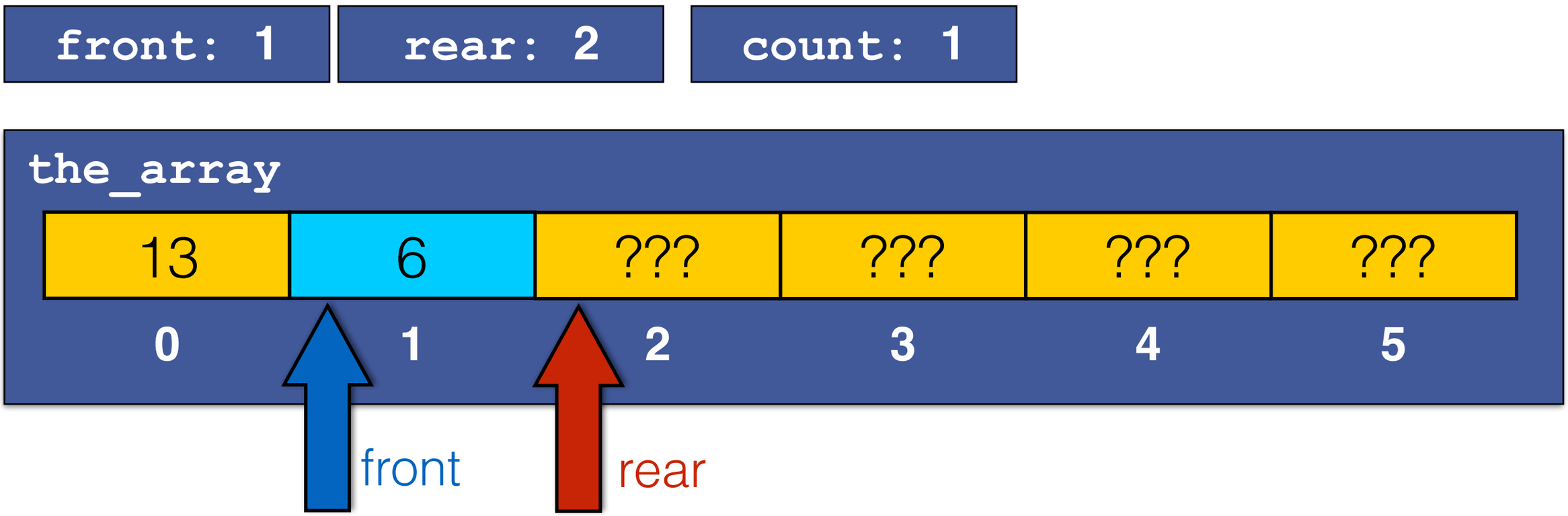
wasteful | ˈweɪstfʊl, -f(ə)l |

adjective

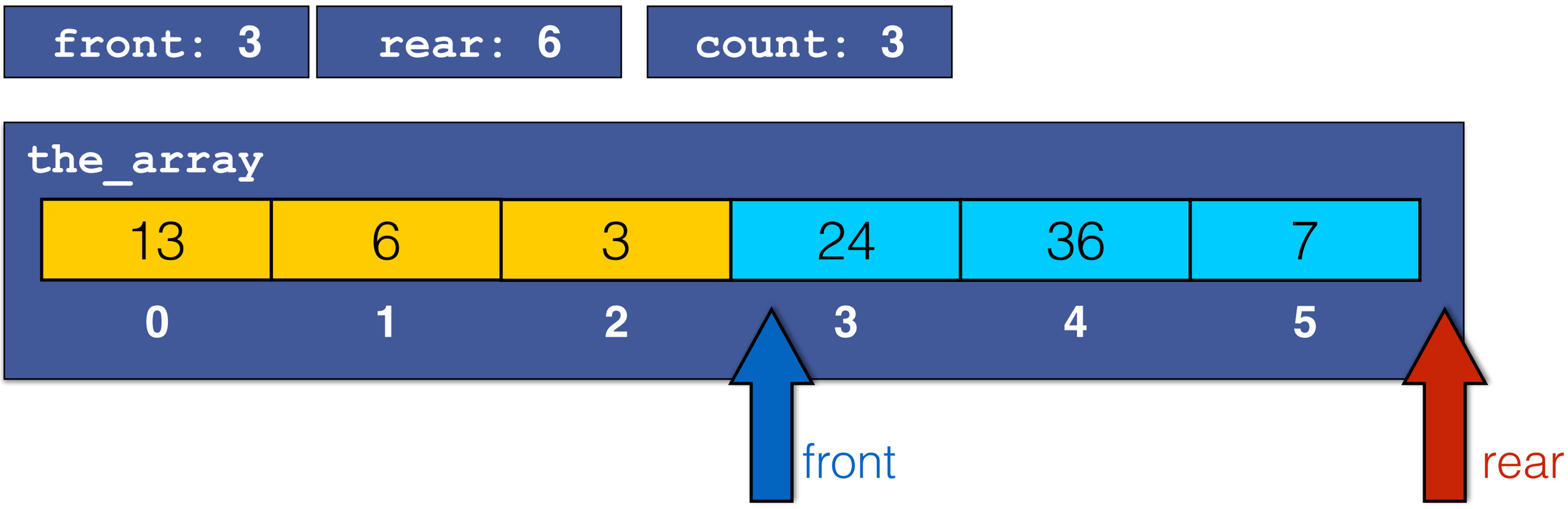
(of a person, action, or process) using or expending something of value carelessly, extravagantly, or to no purpose: *wasteful energy consumption*.

DERIVATIVES

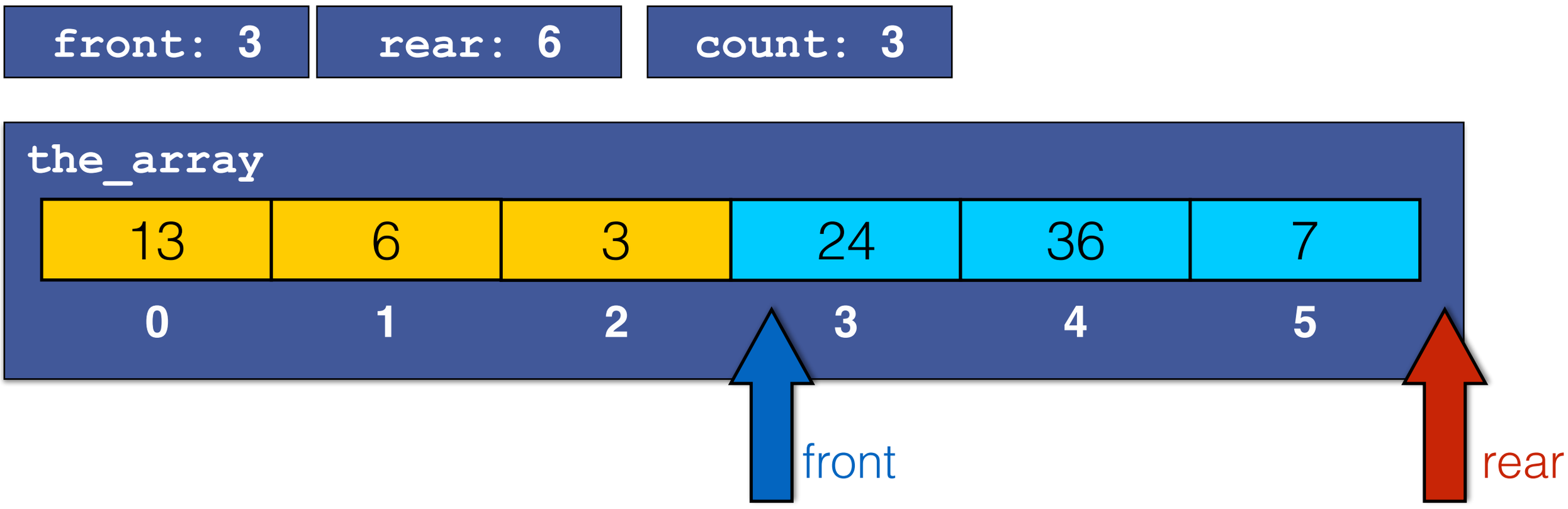
wastefully adverb ,
wastefulness noun


front: 1
rear: 2
count: 1
the_array
13
6
???
???
???
???
0
1
2
3
4
5
front
rear

Implementation problem

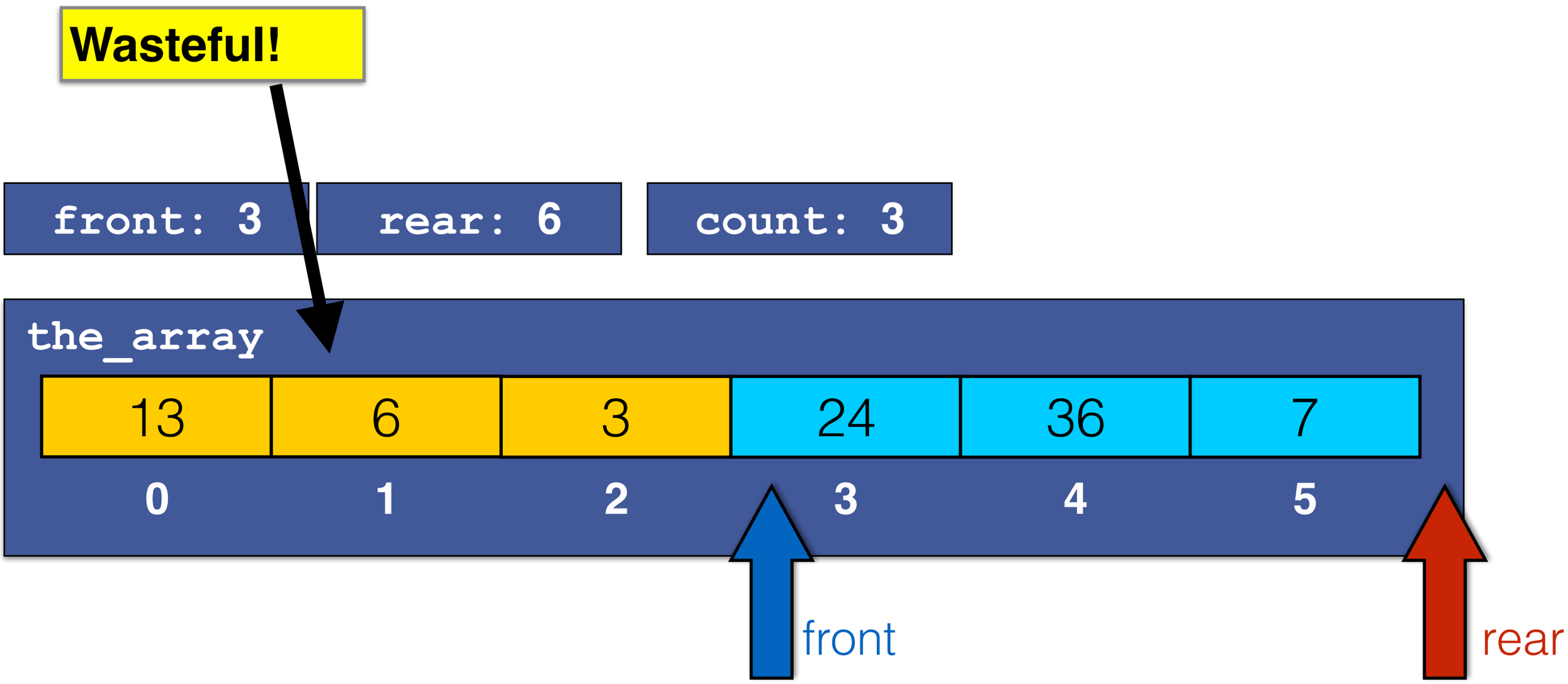


Implementation problem



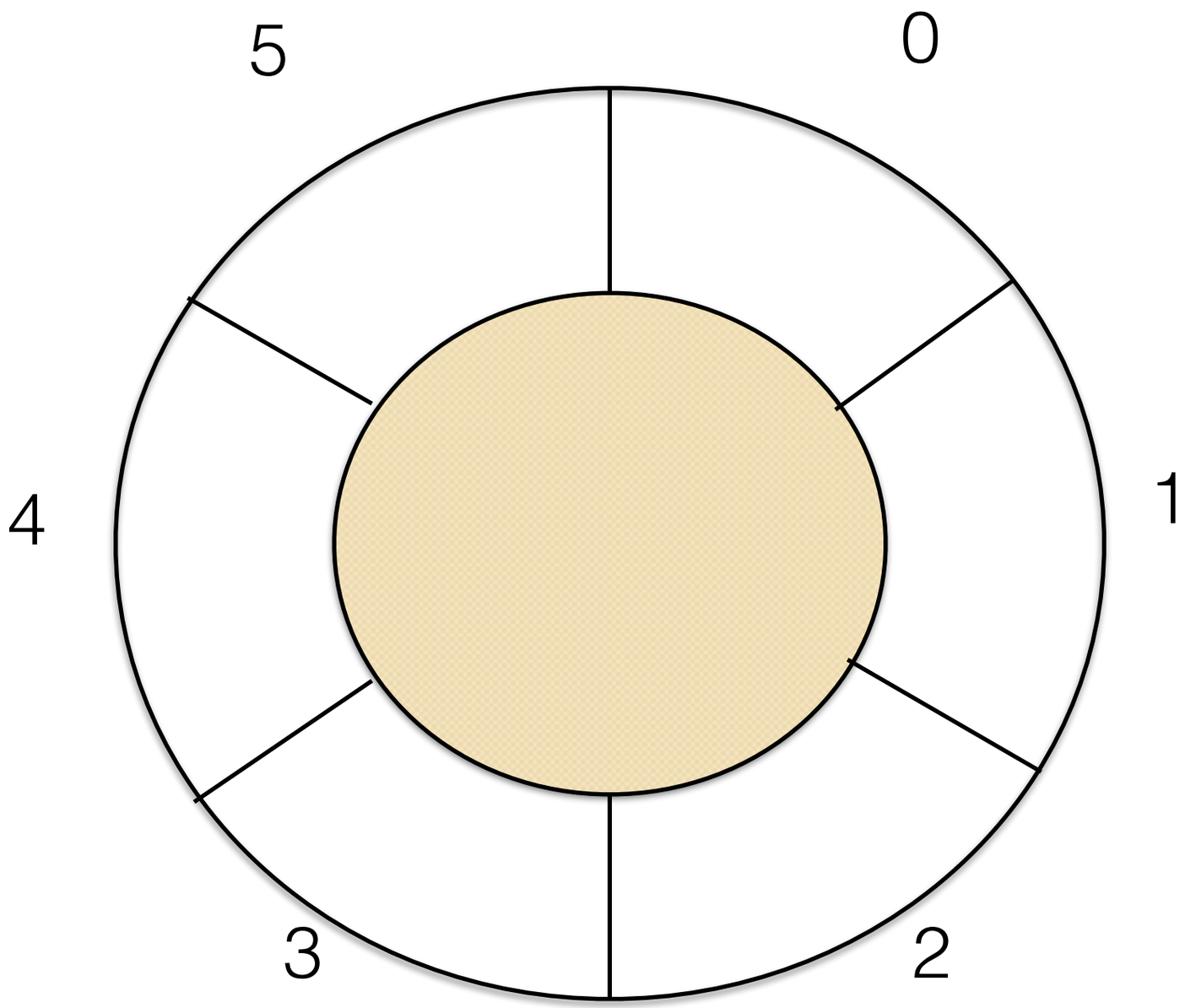

```
def is_full(self):
    return self.rear >= len(self.the_array)
```

Implementation problem

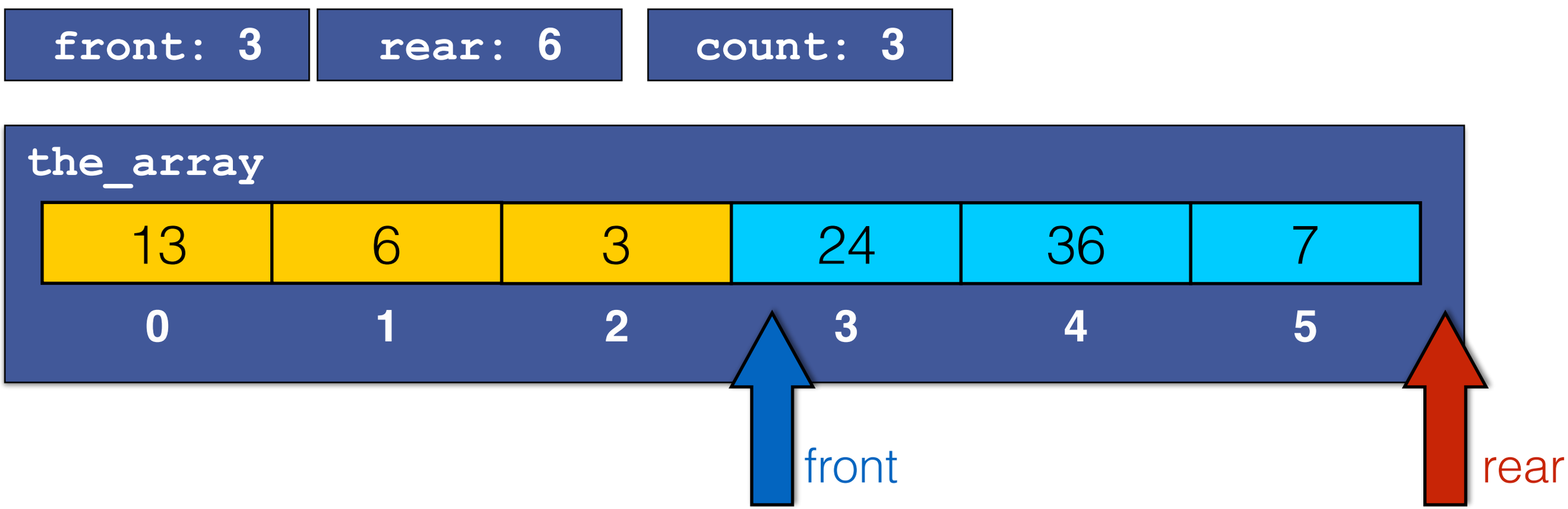


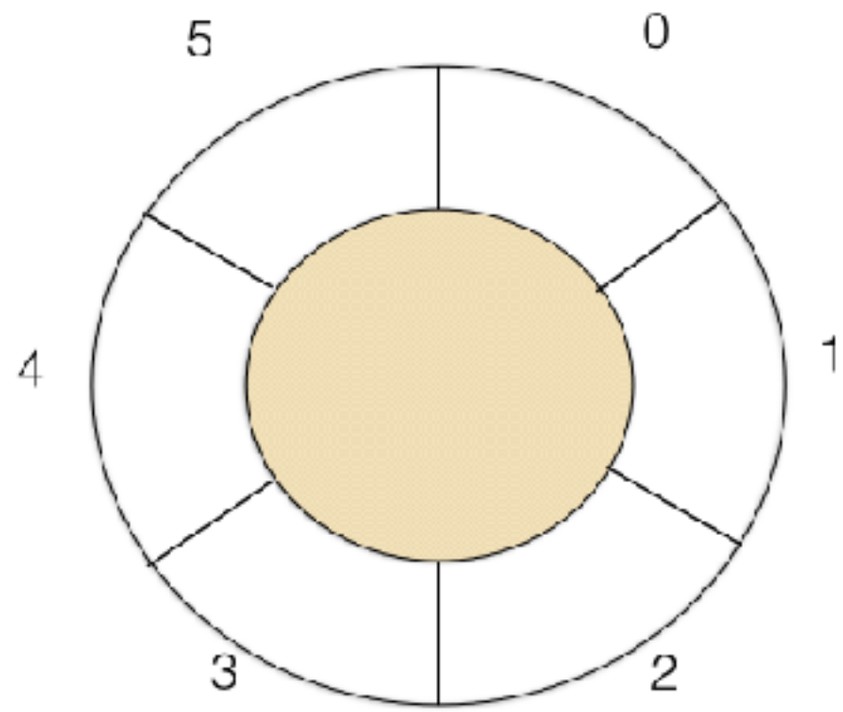

```
def is_full(self):
    return self.rear >= len(self.the_array)
```

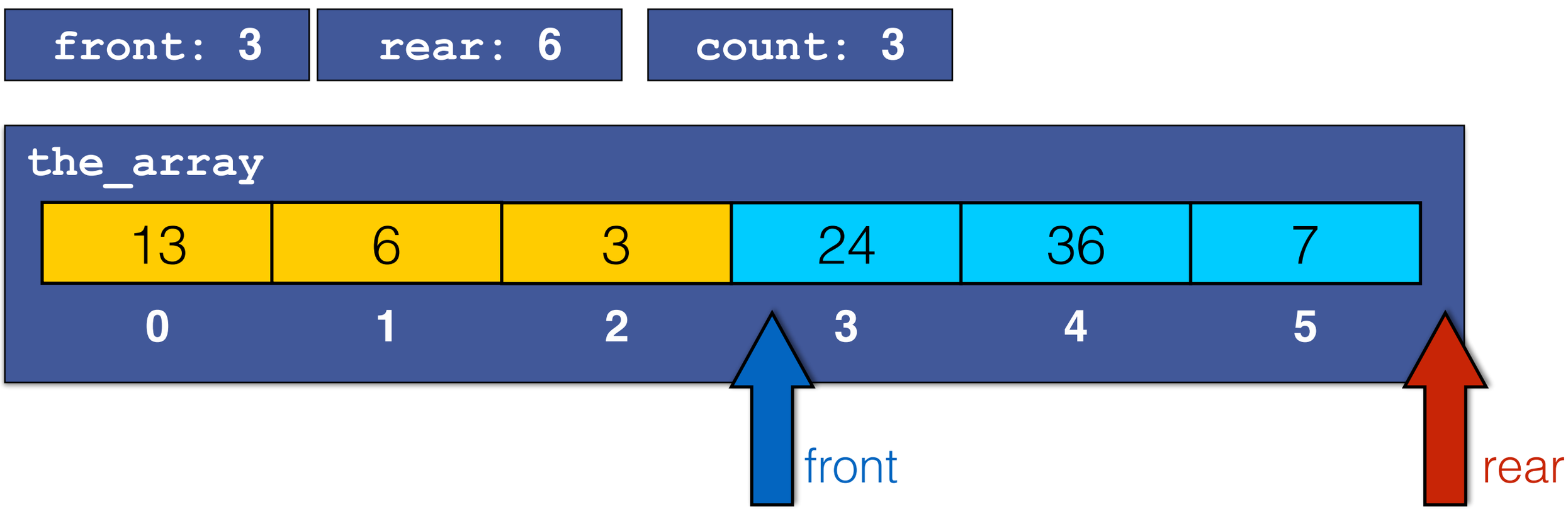
Solution: Circular Queues

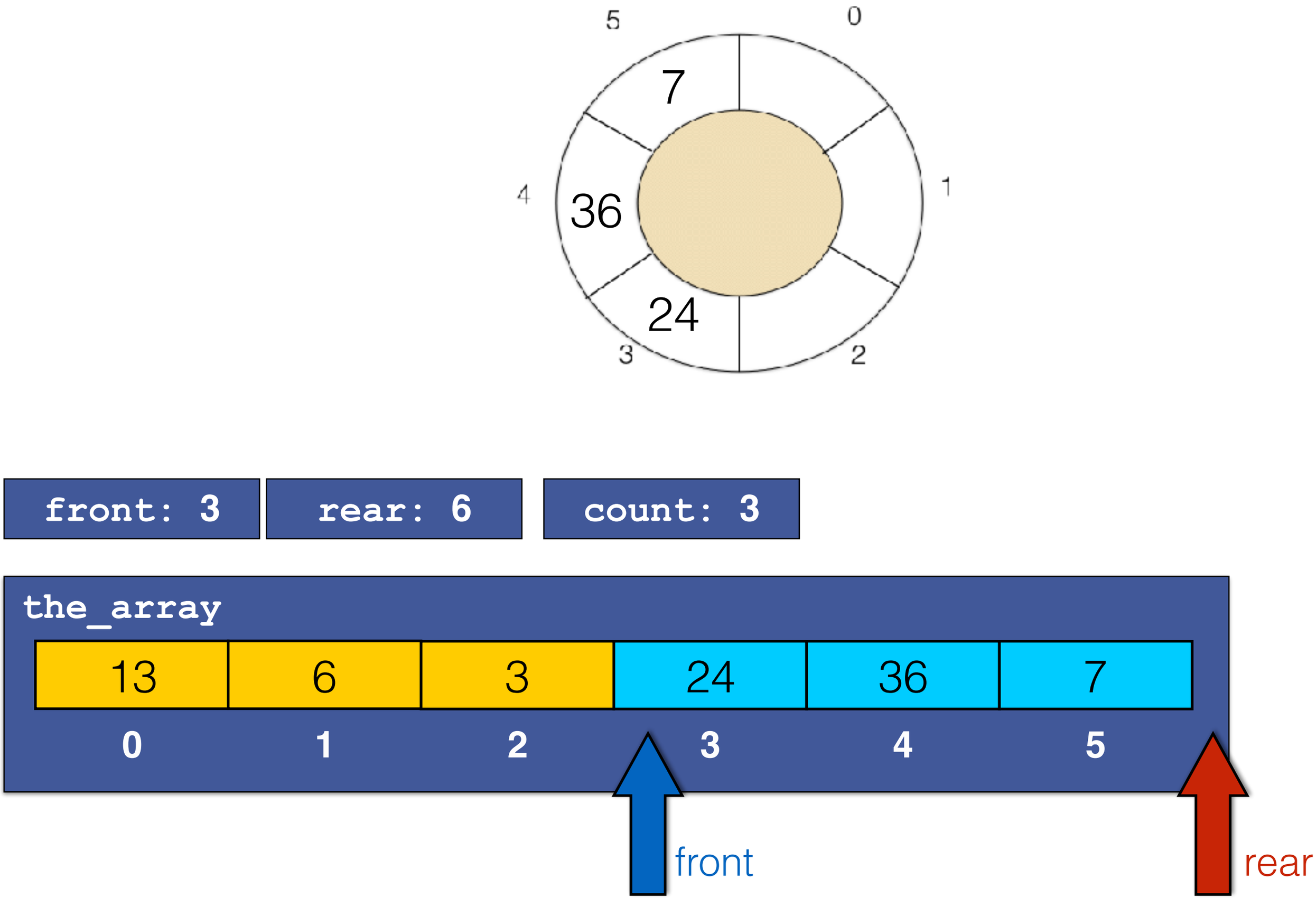


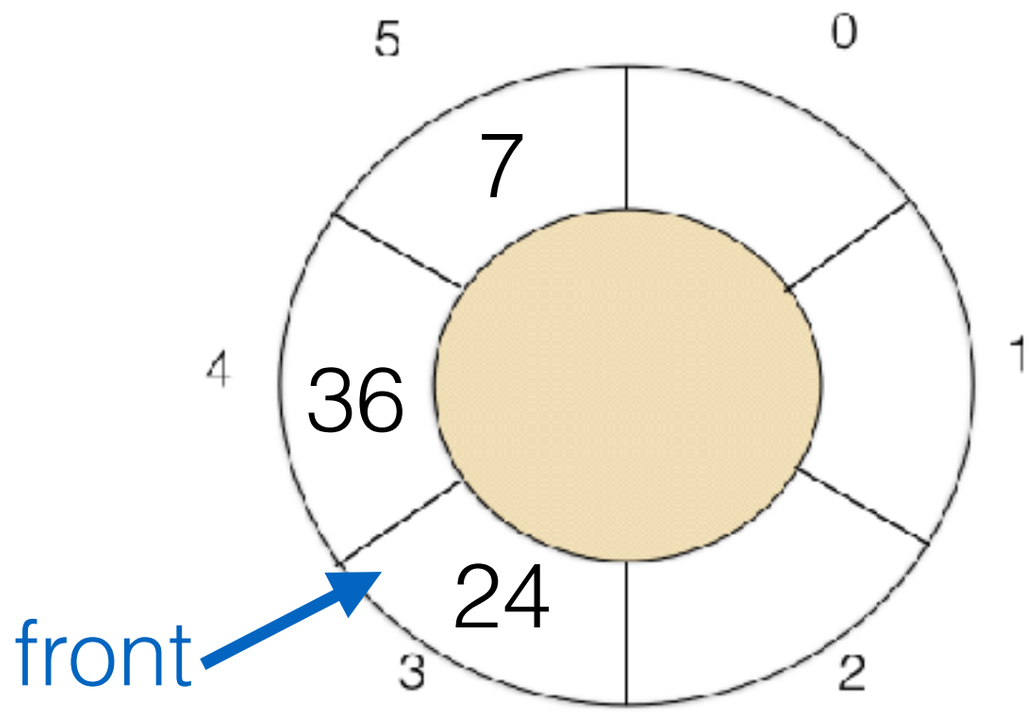
Simulated by allowing **rear** and **front** to wrap around each other

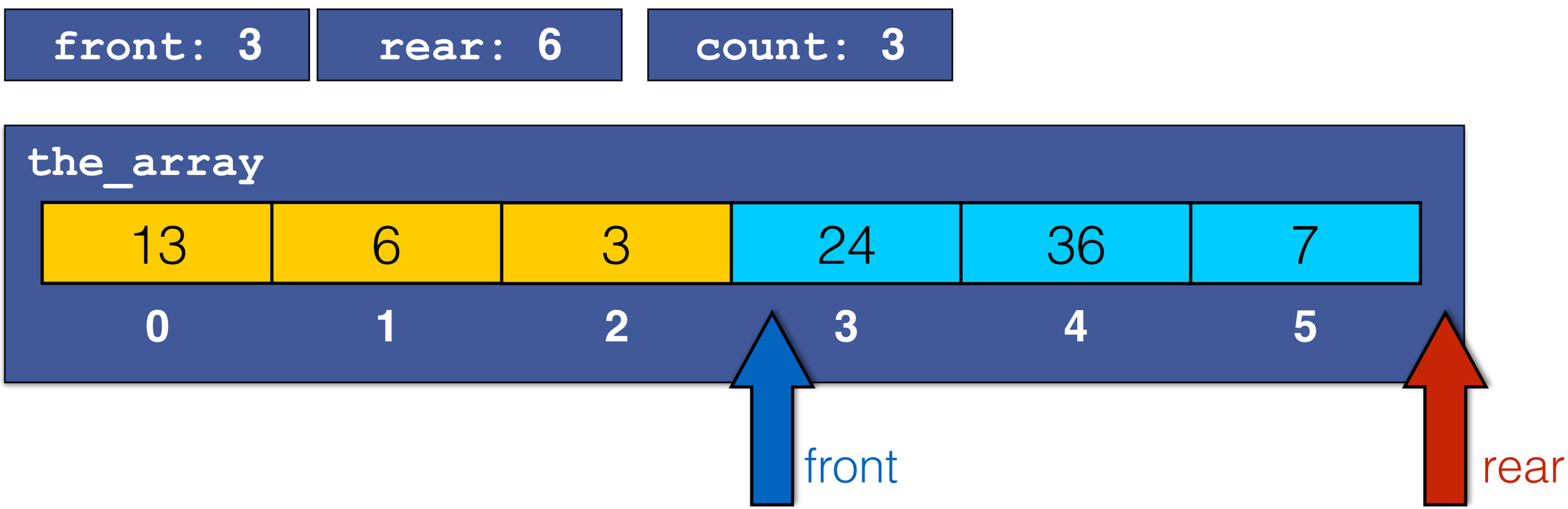

front: 3
rear: 6
count: 3
the_array
13
6
3
24
36
7
0
1
2
3
4
5
front
rear

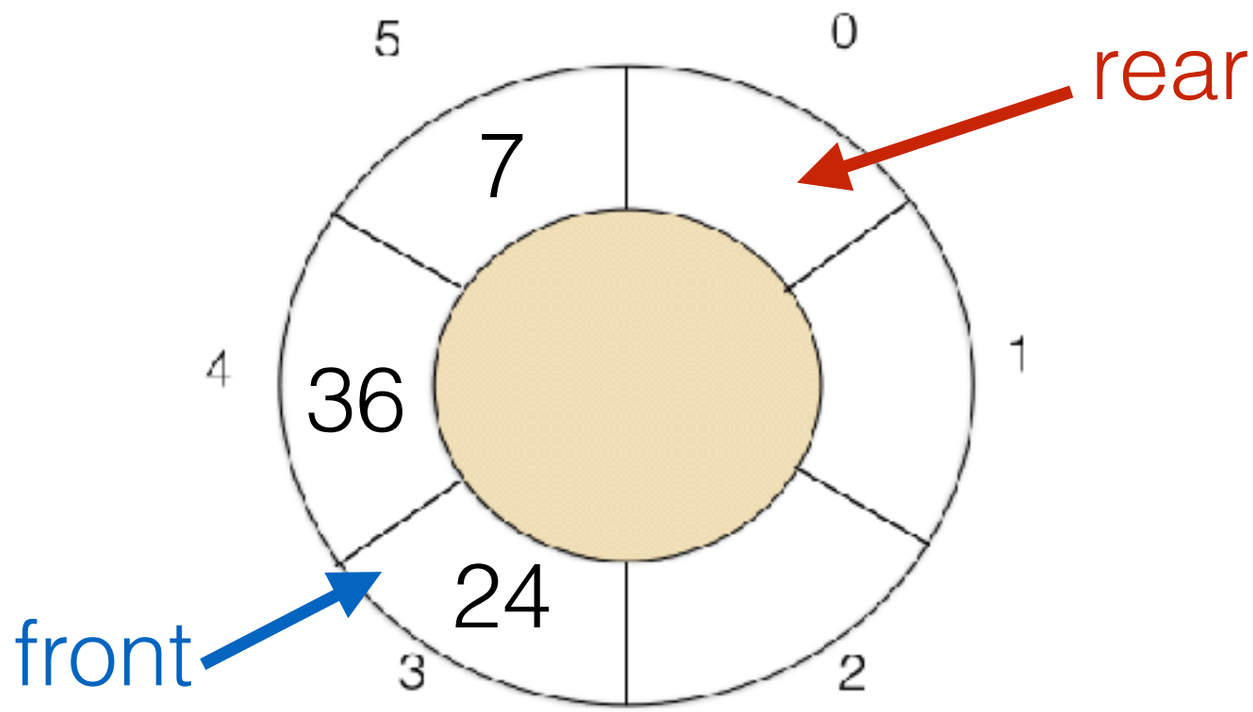

5
0
4
1
3
2

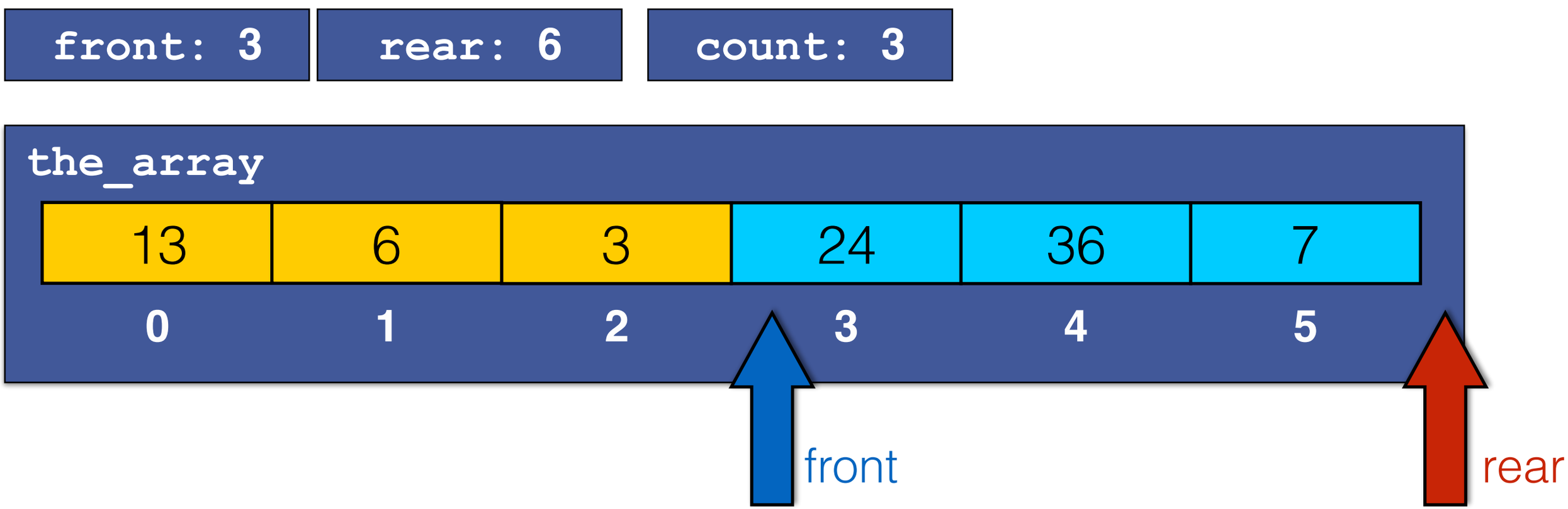

front: 3
rear: 6
count: 3
the_array
13
6
3
24
36
7
0
1
2
3
4
5
front
rear


5
0
7
4
36
1
24
3
2
front: 3
rear: 6
count: 3
the_array
13
6
3
24
36
7
0
1
2
3
4
5
front
rear

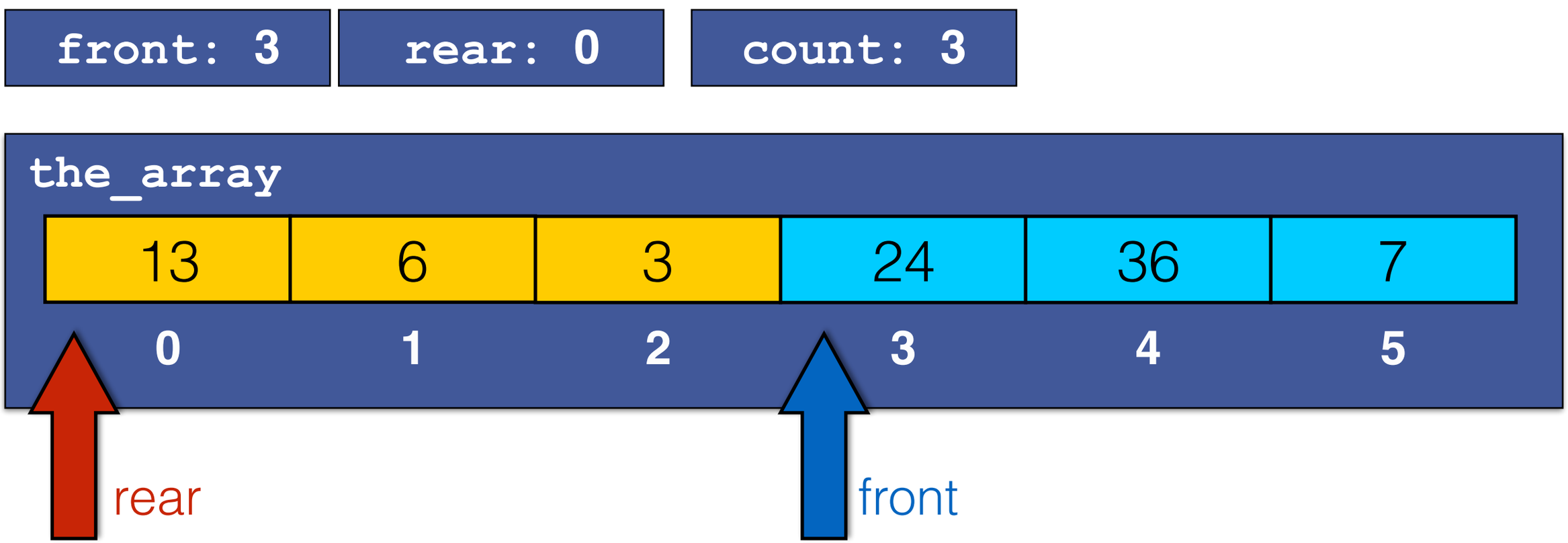

5
0
7
4
36
1
24
front
3
2


front: 3
rear: 6
count: 3
the_array
13
6
3
24
36
7
0
1
2
3
4
5
front
rear

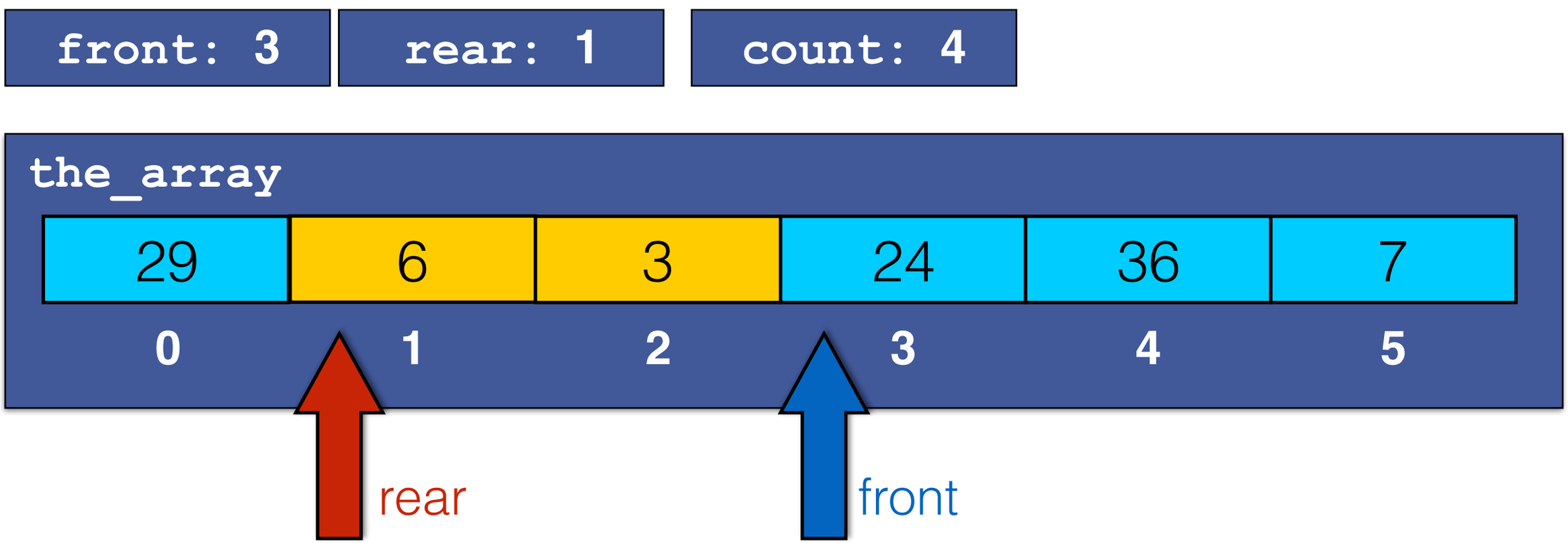

5
0
rear
7
4
36
1
24
front
3
2


front: 3
rear: 6
count: 3
the_array
13
6
3
24
36
7
0
1
2
3
4
5
front
rear

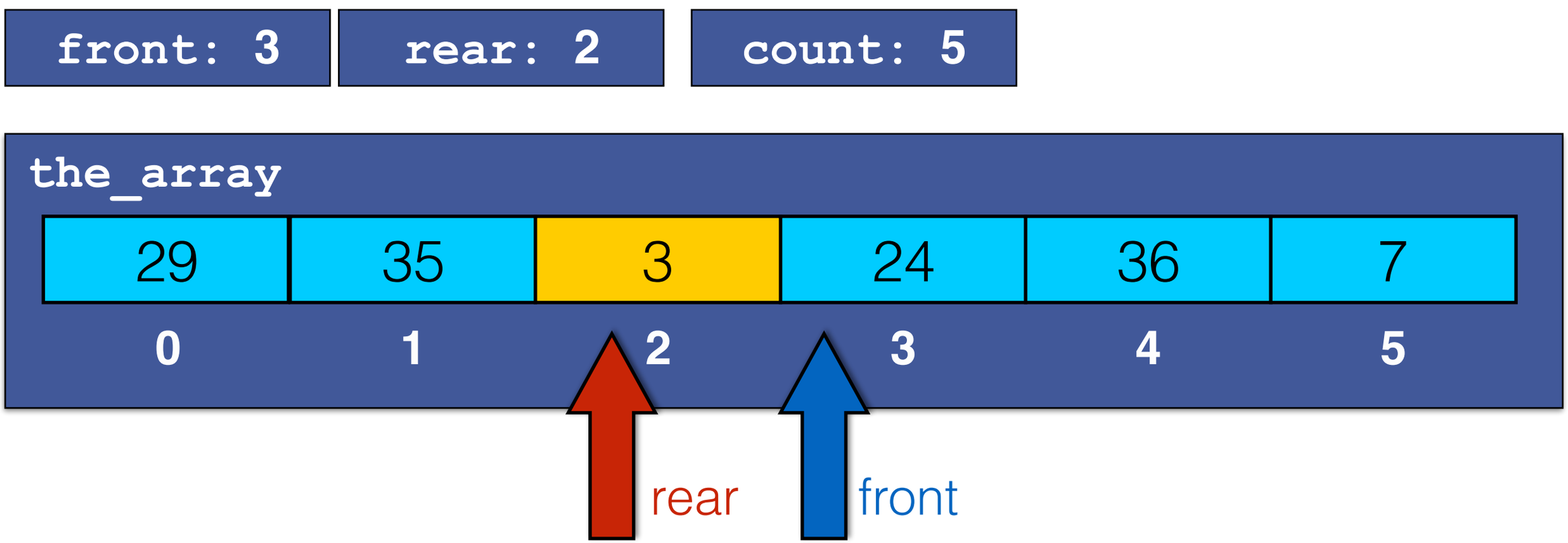
- After appending 7



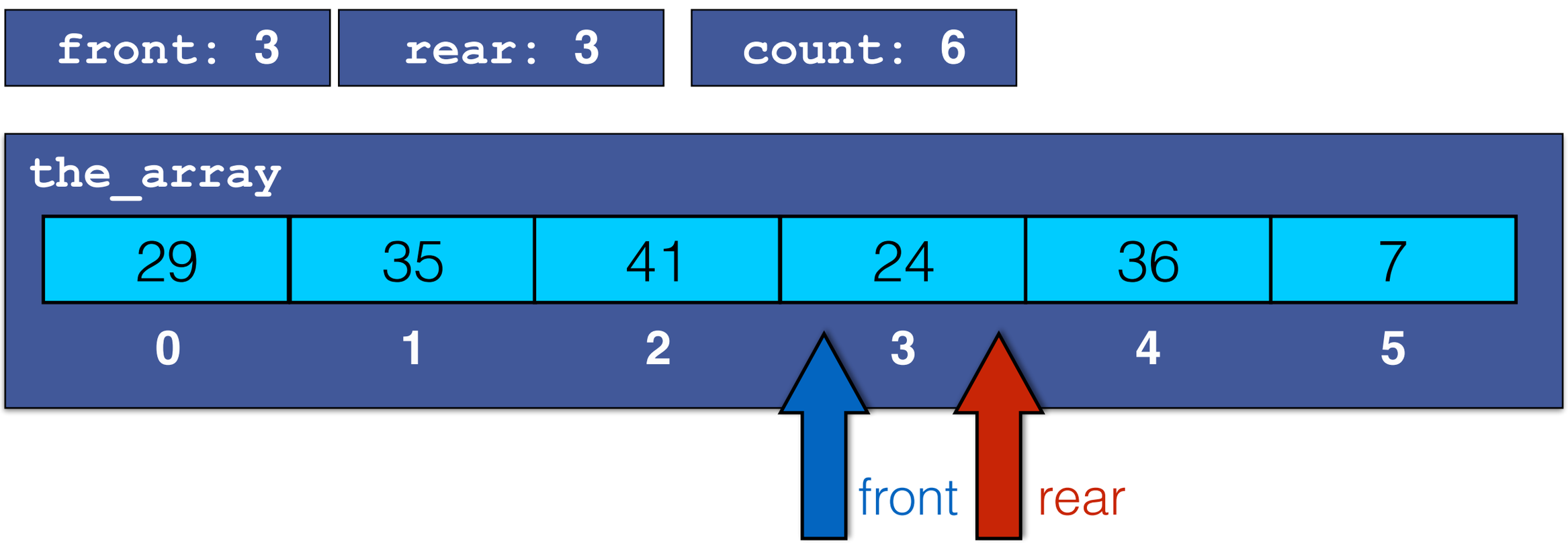
- After appending 7
- Append 29



- After appending 7
- Append 29
- Append 35

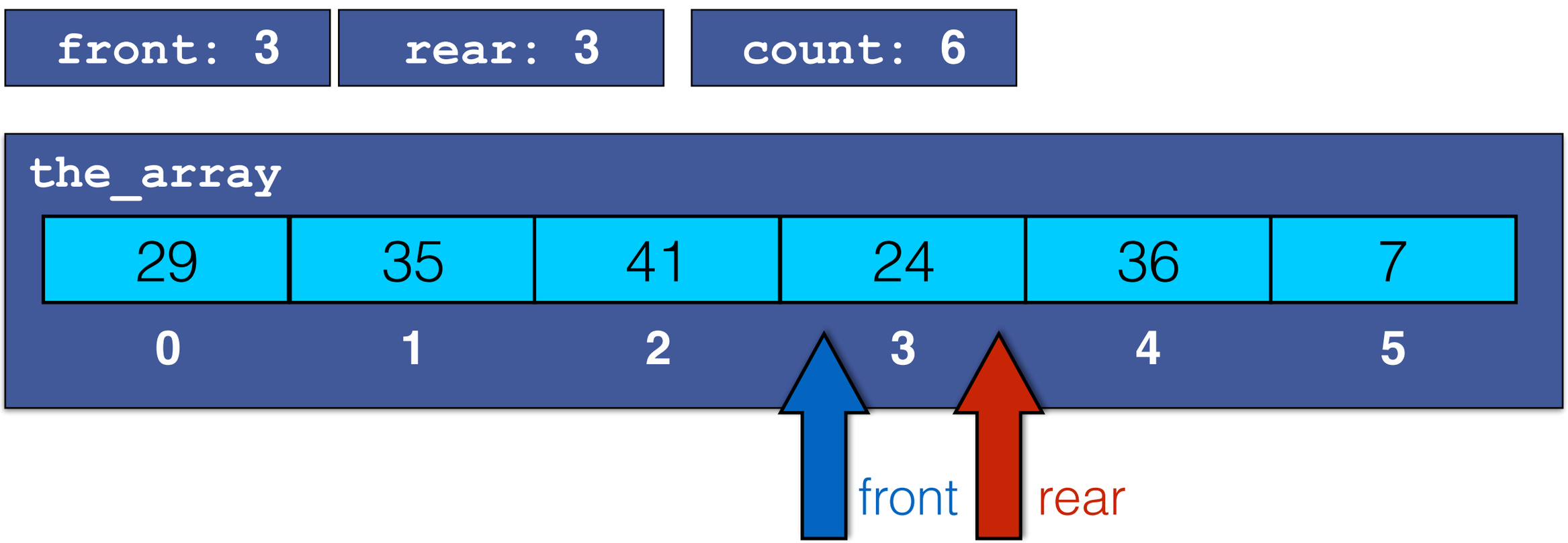


- After appending 7
- Append 29
- Append 35
- Append 41



- After appending 7
- Append 29
- Append 35
- Append 41

Important: Instead of using rear, to determine if the queue is full, we now need to use count.



Creating a circular Queue

```
def __init__(self, size):
    assert size > 0, "Size should be positive"
    self.the_array = size*[None]
    self.count = 0
    self.rear = 0
    self.front = 0
```

Creating a circular Queue

```
def __init__(self, size):
    assert size > 0, "Size should be positive"
    self.the_array = size*[None]
    self.count = 0
    self.rear = 0
    self.front = 0
```

Complexity is O(N)

Methods for Circular Queue

```
def is_empty(self):
    return self.count == 0
```

Methods for Circular Queue

```
def is_empty(self):
    return self.count == 0

def is_full(self):
    return self.count >= len(self.the_array)
```

Methods for Circular Queue

```
def is_empty(self):
    return self.count == 0

def is_full(self):
    return self.count >= len(self.the_array)

def reset(self):
    self.front = 0
    self.rear = 0
    self.count = 0
```

Methods for Circular Queue

```
def is_empty(self):
    return self.count == 0

def is_full(self):
    return self.count >= len(self.the_array)

def reset(self):
    self.front = 0
    self.rear = 0
    self.count = 0
```

Use **count,** not rear

Methods for Circular Queue

```
def is_empty(self):
    return self.count == 0

def is_full(self):
    return self.count >= len(self.the_array)

def reset(self):
    self.front = 0
    self.rear = 0
    self.count = 0
```

Use **count,** not rear

Complexity is O(1)

Implementation of Append for a Circular Queue

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
```

Implementation of Append for a Circular Queue

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
```

Implementation of Append for a Circular Queue

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
    if self.rear == len(self.the_array):
        self.rear = 0
```

Implementation of Append for a Circular Queue

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
    if self.rear == len(self.the_array):
        self.rear = 0
    self.count += 1
```

Implementation of Append for a Circular Queue

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
    if self.rear == len(self.the_array):
        self.rear = 0
    self.count += 1
```

Implementation of Append for a Circular Queue

```
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
    if self.rear == len(self.the_array):
        self.rear = 0
    self.count += 1
```

If rear points outside of the_array but I know **the queue is not full**

You know that *len(self.the_array) = 6* and *self.rear = 5*

(self.rear + 1) **%** *len(self.the_array)* is equal to…

(self.rear + 1) **%** *len(self.the_array)*

(5 + 1) **%** *6*

6 **%** *6 = 0*

You know that *len(self.the_array) = 6* and *self.rear = 4*

(self.rear + 1) **%** *len(self.the_array)* is equal to…

(self.rear + 1) **%** *len(self.the_array)*

(4 + 1) **%** *6*

5 **%** *6 = 5*

```python
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear = (self.rear+1)% len(self.the_array)
    self.count += 1
```

```python
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear = (self.rear+1)% len(self.the_array)
    self.count += 1
```

```python
def append(self, new_item):
    assert not self.is_full(), "Queue is full"
    self.the_array[self.rear] = new_item
    self.rear += 1
    if self.rear == len(self.the_array):
        self.rear = 0
    self.count += 1
```

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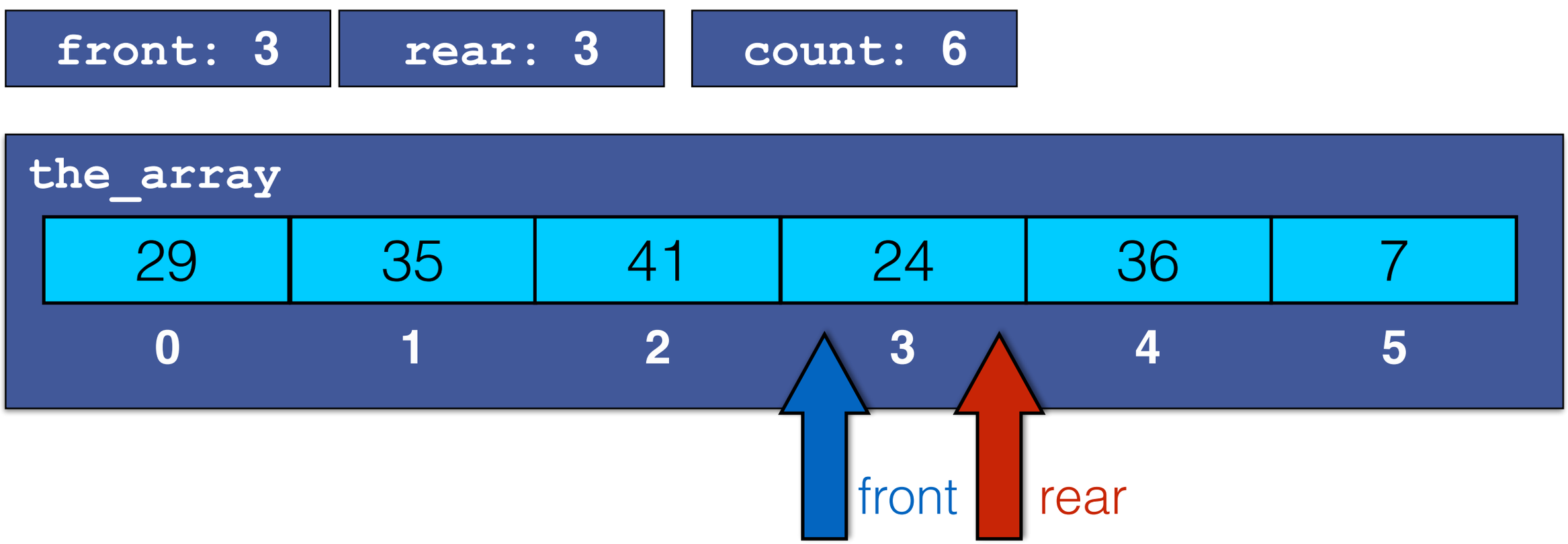
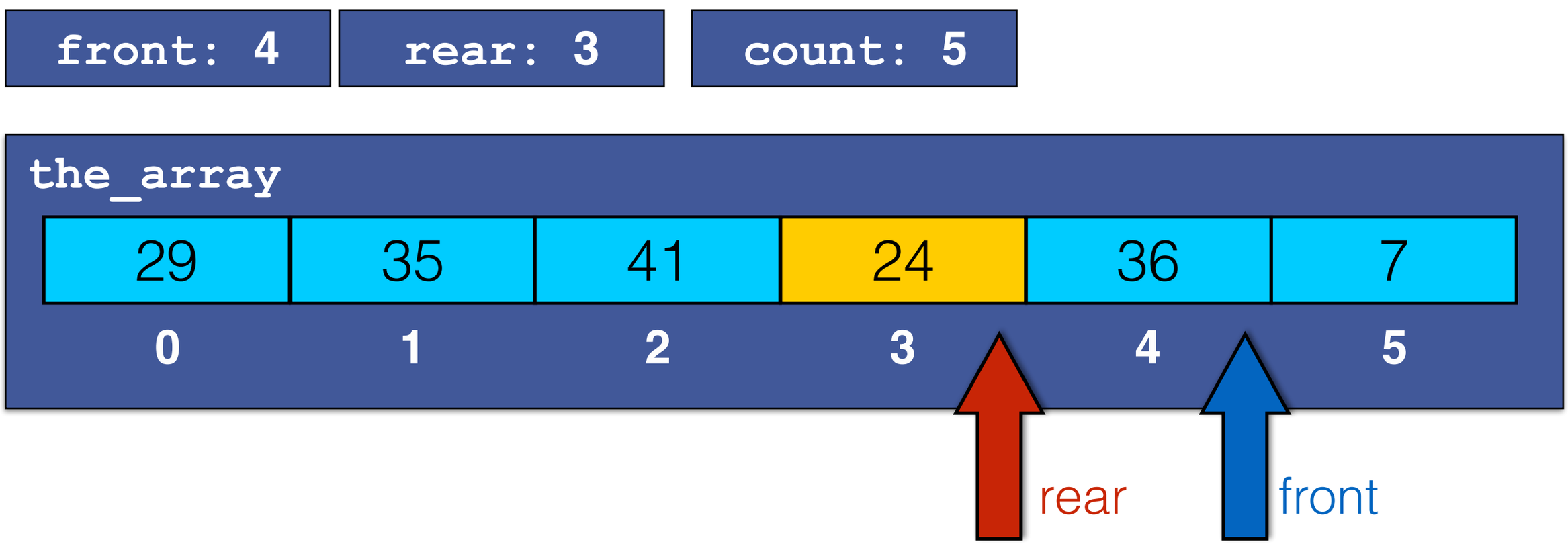
```

Circular queue: both front and rear wrap



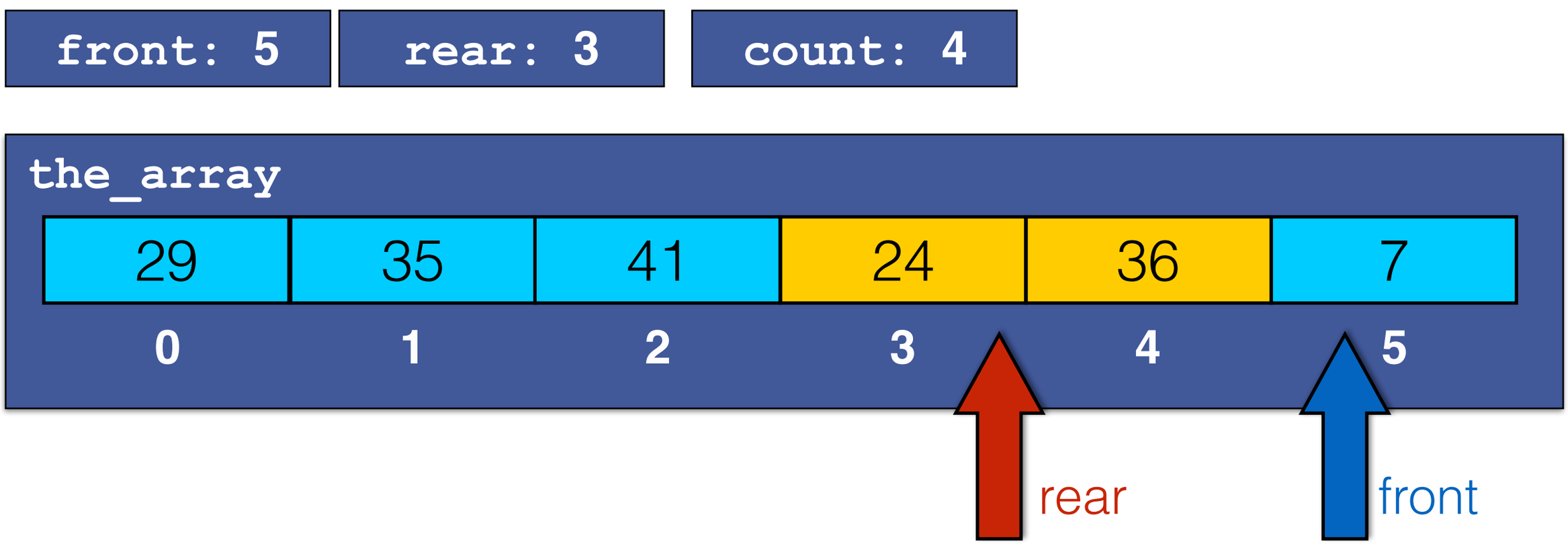
Circular queue: both front and rear wrap

- Serve item (returns 24)



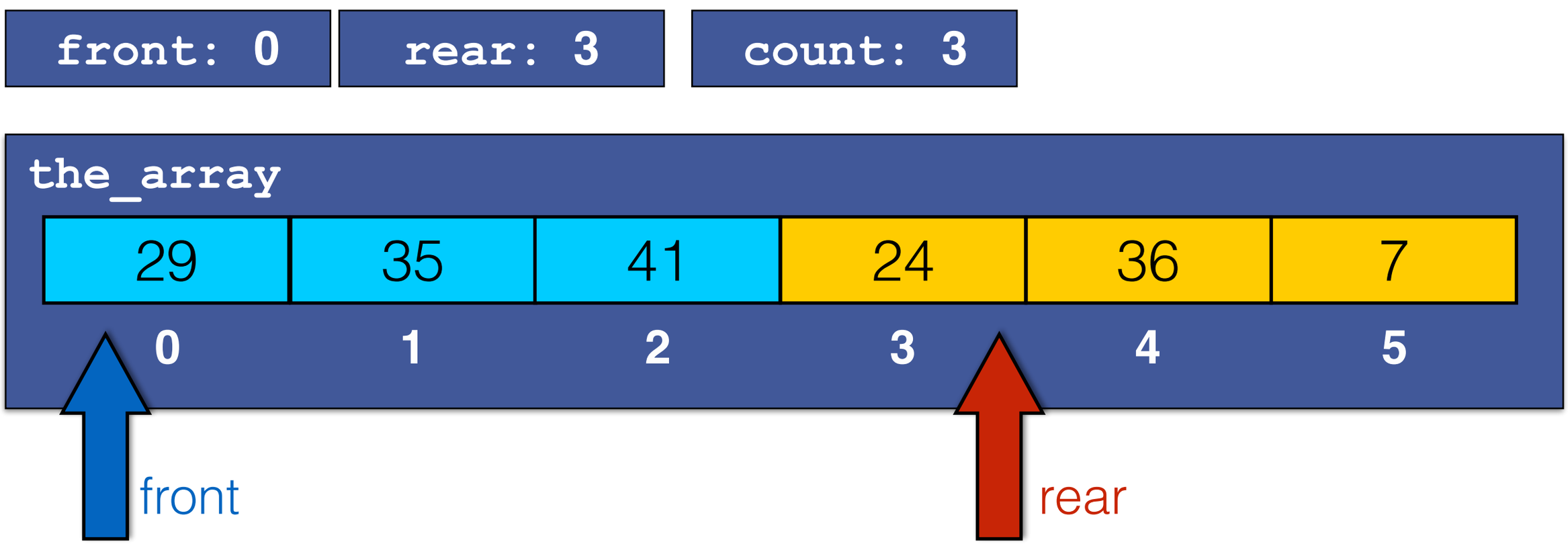
Circular queue: both front and rear wrap

- Serve item (returns 24)
- Serve item (returns 36)



Circular queue: both front and rear wrap

- Serve item (returns 24)
- Serve item (returns 36)
- Serve item (returns 7)



Implementation of Serve for a Circular Queue

```
def serve(self):
    assert not self.is_empty(), "Queue is empty"
    item = self.the_array[self.front]
    self.front = (self.front+1) % len(self.the_array)
    self.count -=1
    return item
```

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    self.count -=1
    return item
```

```
self.front +=1
if self.front == len(self.the_array):
    self.front = 0
```

Print Queue

- Lets implement it as a function within the Queue ADT. So, it has access to the implementation.
- Do not modify the queue, just **print** its elements

Print Queue

```
def print_items(self):
    index = self.front
    for _ in range(self.count):
        print(str(self.the_array[index]))
        index = (index+1) % len(self.the_array)
```

Print Queue

Anonymous variable

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def print_items(self):
    index = self.front
    for _ in range(self.count):
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Print Queue

Anonymous variable

print as many items as available in the queue

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Convert to string whatever is stored

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```

Convert to string whatever is stored

Increase index or make it zero if it points to outside of the_array

Some Queue Applications

- Scheduling and buffering
  - Printers
  - Keyboards
  - Executing asynchronous procedure calls

Summary

- Queues
  - Array implementation
    - Linear
    - Circular
  - Basic operations
  - Their complexity