



# Queues

**Notes from Charlie Obimbo  
and revised by Yan Yan.**



# Contents

1. Definition of Queues
2. Queues Implementation



# Learning Objectives

1. Define the data structure of the queue ADT
2. Implement the operations of the queue ADT.
3. Describe the advantages and disadvantages of linked list implementation and array implementation of the queue.



# Review of Stacks and Queues

## ◆ Stacks & Queues

– Stacks: Last in First Out



- Queues: First in First Out





# Stack: Definition

- ◆ **Stack**: A stack is an ADT in which items are only inserted on or removed from the top of a stack.
- ◆ **Push** operation inserts an item on the top of the stack.
- ◆ **Pop** operation removes and returns the item at the top of the stack.
- ◆ A *linear* data structure, in which elements are accessed using the LIFO (Last in First Out) Order.

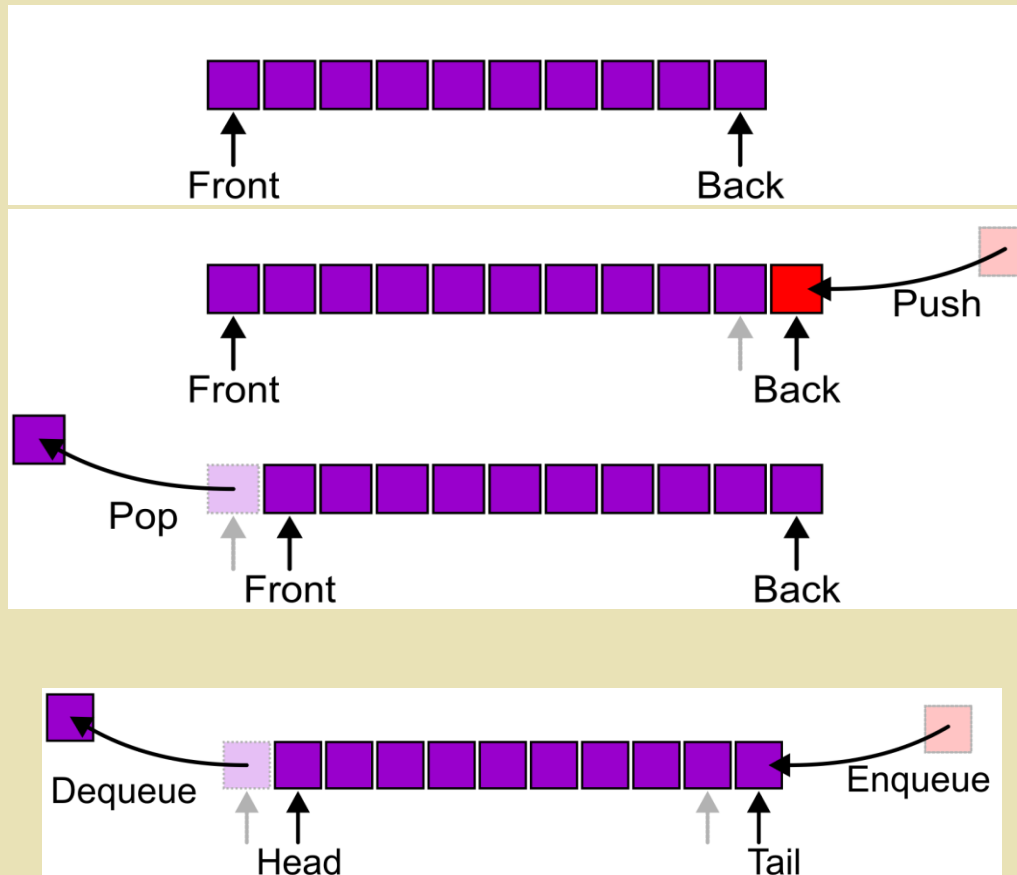


# Queue: Definition

- ◆ **Queue**: A queue is an ADT in which items are inserted at the end of the queue and removed from the front of the queue.
- ◆ **Enqueue** operation inserts an item at the end of the queue.
- ◆ **Dequeue** operation removes and returns the item at the front of the queue.
- ◆ A *linear* data structure, FIFO (First in First Out).

# Queue ADT

- ◆ Insertions and removals are performed individually
- ◆ The object designated as the front of the queue is the object which was in the queue the *longest*







# Queues: Operations

- **Enqueue(queue, x):** inserts **x** at end of the queue
- **Dequeue(queue):** removes and returns the element at the front of the queue
- **Peek(queue) (or front):** returns the element at the front without removing it
- **IsEmpty(queue):** indicates whether no elements are stored



# Queues: Operations

## ◆ Errors:

- Attempting the execution of dequeue or front on an empty queue, or enqueue on a full queue





# Time Complexities

- ◆ What are the time complexities of the operations on the queue?
- ◆ We require Enqueue(), Dequeue(), isEmpty() and peek() all take  $O(1)$  time.



# Queues: Exercise

Given numQueue: 5, 9, 1 (front is 5)

- ◆ What are the queue contents after the following?

Enqueue(numQueue, 4)

Enqueue(numQueue, 7)

- ◆ Following the previous operations, What is returned by Dequeue(numQueue)?

What operation determines if the queue contains no items?





# Queues: Exercise

Given numQueue: 5, 9, 1 (front is 5)

- ◆ What are the queue contents after the following?

Enqueue(numQueue, 4)

Enqueue(numQueue, 7)    5,9,1,4,7

- ◆ Following the previous operations, What is returned by Dequeue(numQueue)? 5

What operation determines if the queue contains no items? **IsEmpty**



# Queues: Exercise

Given numQueue: 90, 20, 97

- ◆ What are the queue's contents after the following operations?

Enqueue(numQueue, 14)

Dequeue(numQueue)

Dequeue(numQueue)



# Queues: Exercise

Given numQueue: 90, 20, 97

- ◆ What are the queue's contents after the following operations?

Enqueue(numQueue, 14)

Dequeue(numQueue)

Dequeue(numQueue)

97,14



# Queues

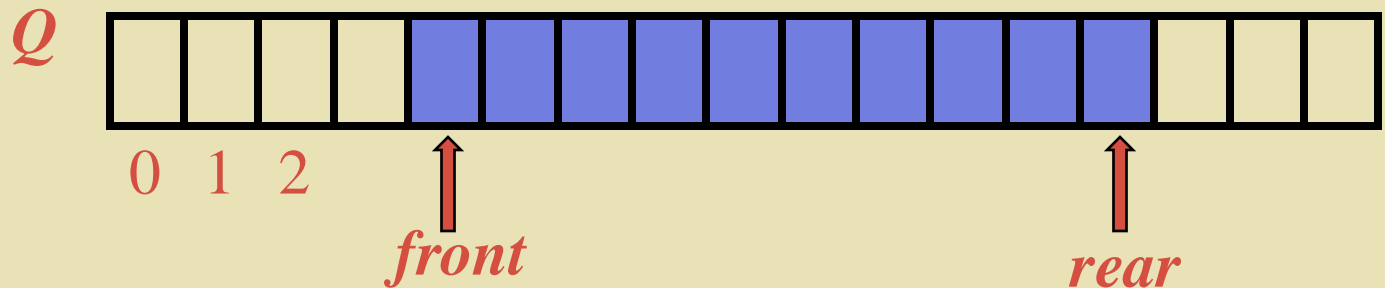
## ◆ Implementation:

- linked list
- array



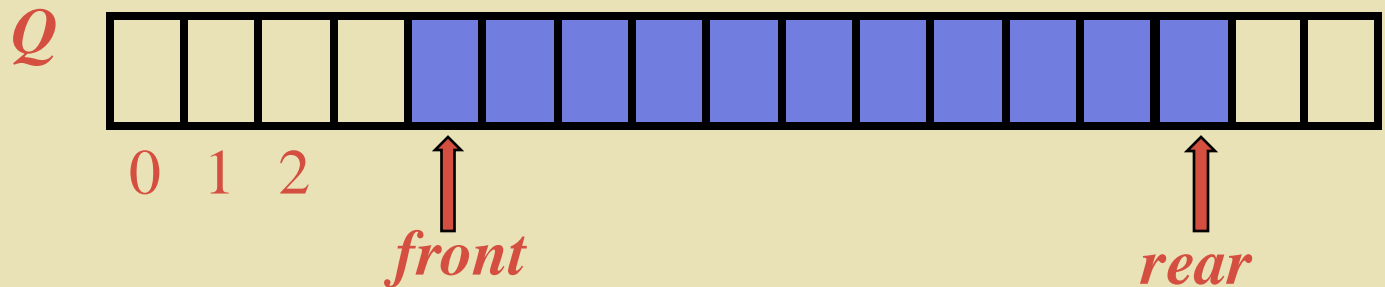
# Array-based Implementation

- ◆ Define an array
- ◆  $Q$  – index between front and rear
  - *rear* – add element
  - *front* – remove element
- ◆ Rest of the element in the array are free space



# Array-based Implementation

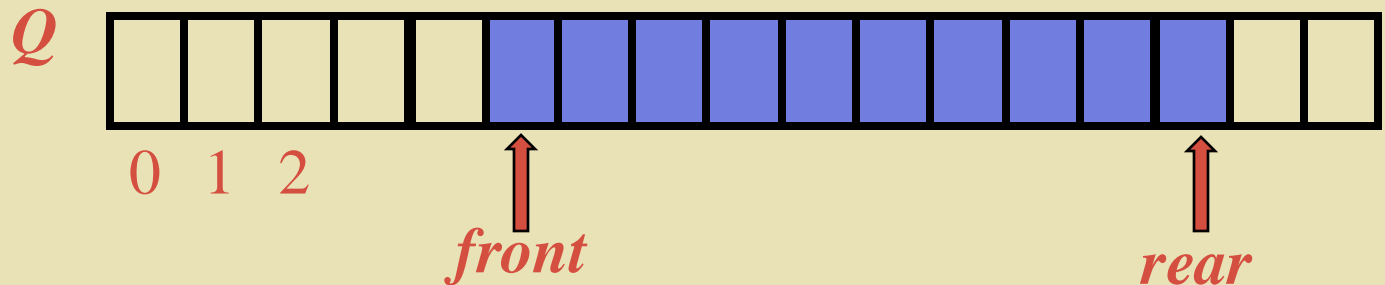
- ◆ Define an array
- ◆  $Q$  – index between front and rear
  - *rear* – add element
  - *front* – remove element
- ◆ Rest of the element in the array are free space
  - Add element to the  $Q$





# Array-based Implementation

- ◆ Define an array
- ◆  $Q$  – index between front and rear
  - *rear* – add element
  - *front* – remove element
- ◆ Rest of the element in the array are free space
  - Remove element to the  $Q$



# Array-based Implementation

## ◆ Pseudocode

`int A[n]`

`//initialization`

`front = -1`

`rear = -1`

`//Check if the Queue is empty`

`IsEmpty () {`

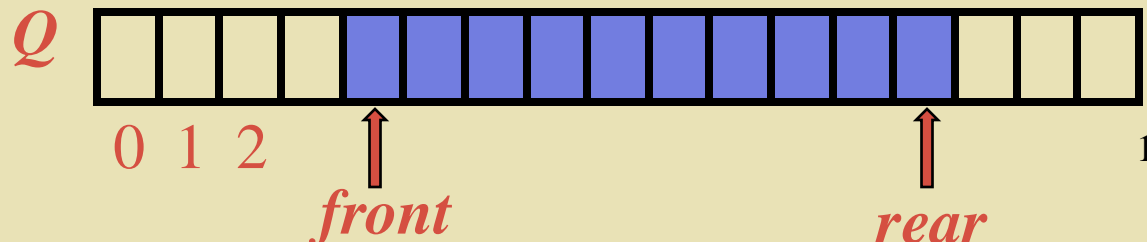
`if front == -1 && rear == -1`

`return true`

`else`

`return false`

`}`



# Array-based Implementation

## ◆ Pseudocode

//Check if the Queue is full

IsFull () {

if rear == size(A) -1

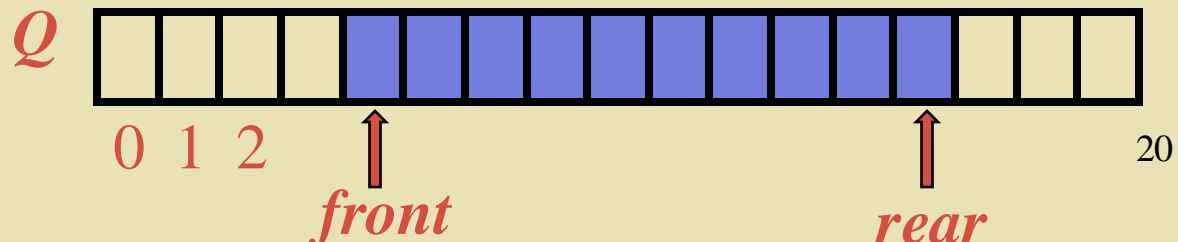
    print “Queue is full”

    return true

else

    return false

}

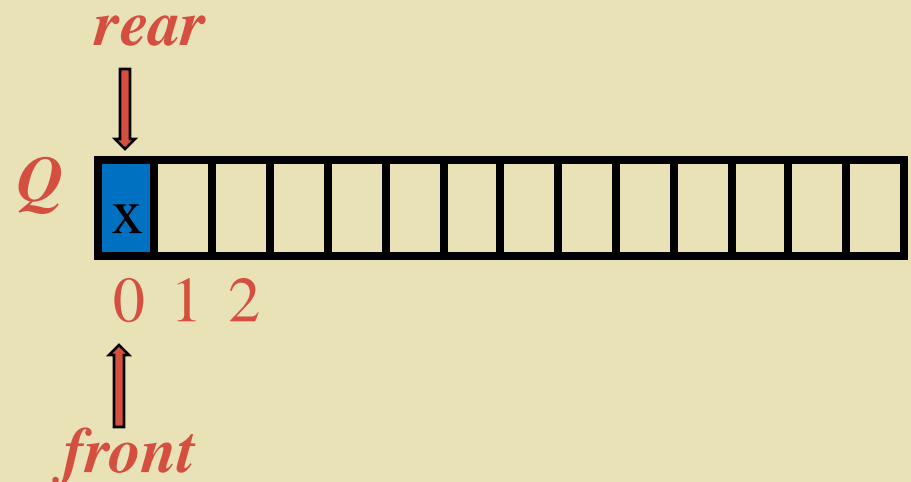
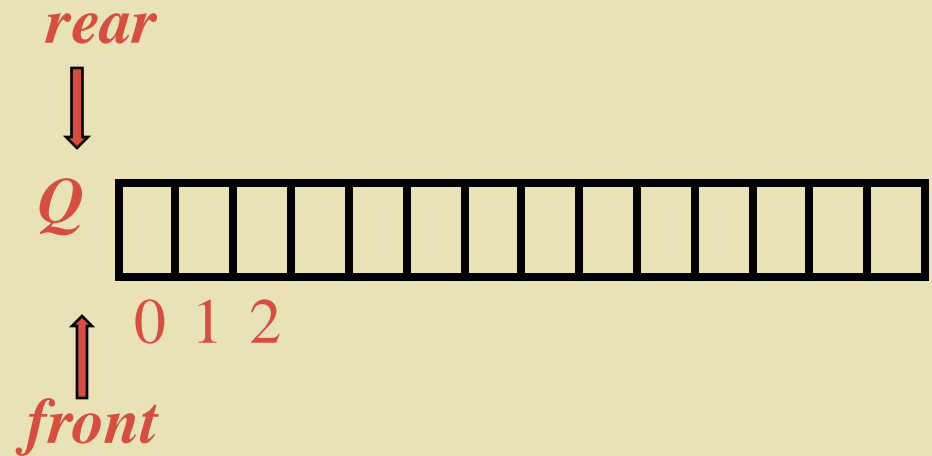




# Array-based Implementation

//Enqueue function

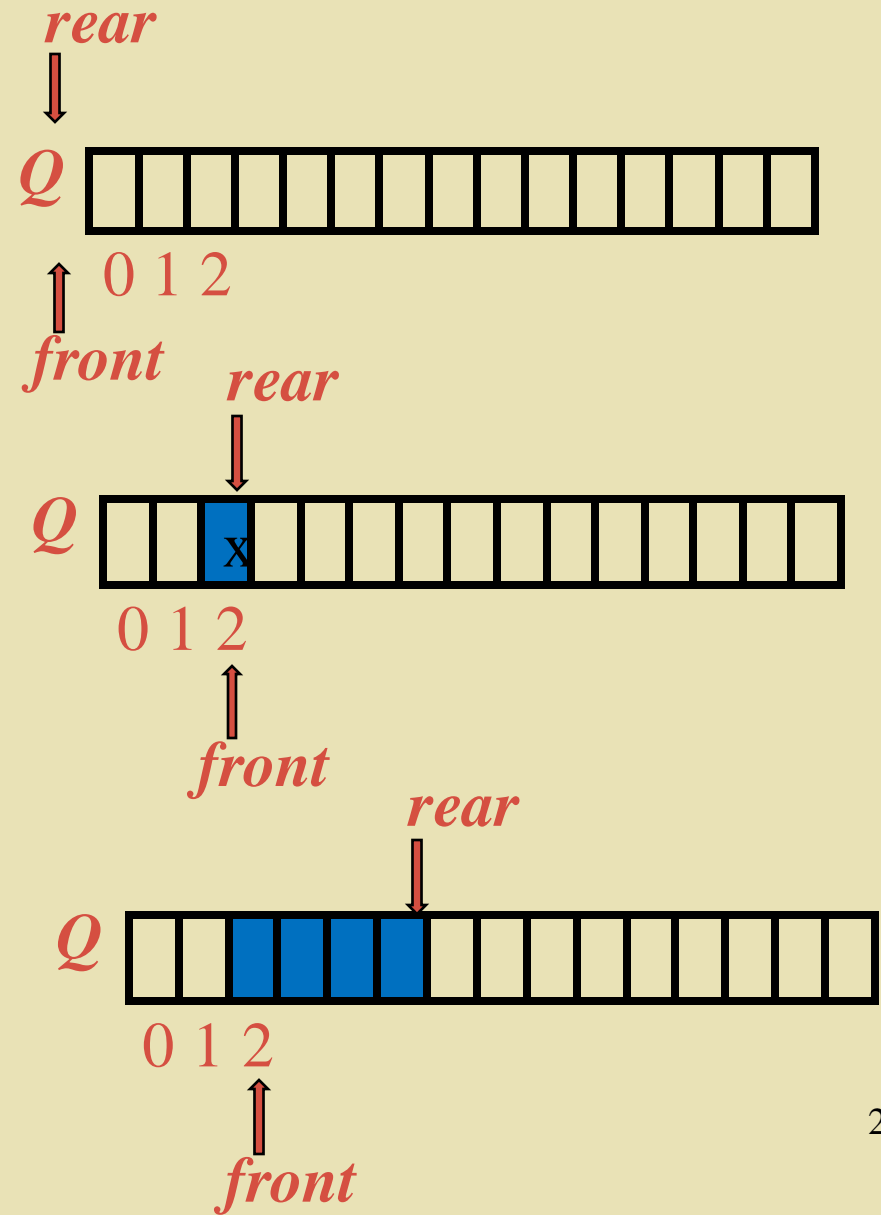
```
Enqueue (x) {  
  if IsFull()  
    return  
  else if IsEmpty() {  
    front = 0  
    rear = 0  
  }  
  else {  
    rear = rear + 1  
  }  
  A[rear] = x  
}
```



# Array-based Implementation

//Dequeue function

```
Dequeue () {  
  if IsEmpty()  
    print "queue empty"  
    return  
  else if front == rear {  
    // there is only one element  
    Deq=A[front]  
    front = -1  
    rear = -1  
    return Deq  
  }  
  else front = front + 1  
    return A[front-1]  
}
```

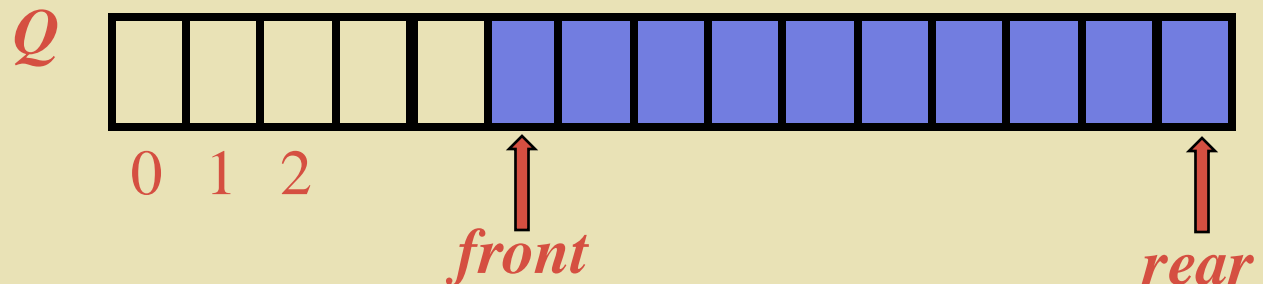


# Array-based Implementation

## ◆ Limitations

- Queue size is bounded by the pre-defined array size
- When *rear* reach the last index in the array, we cannot extend it further
- There could be unused cells in the array

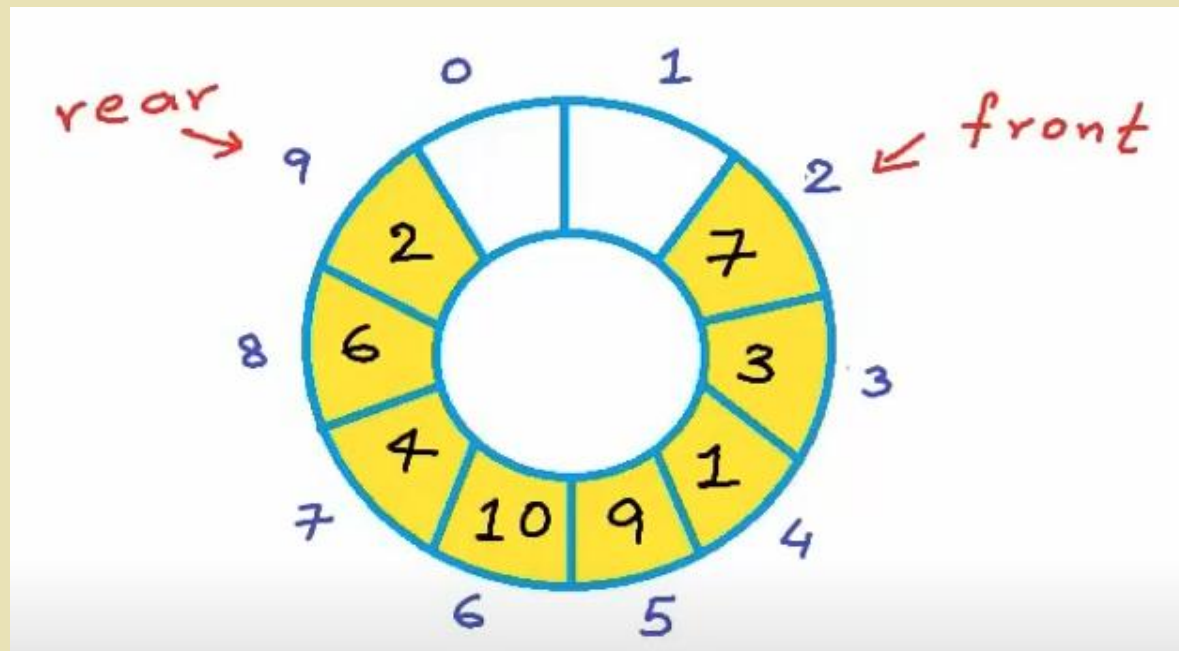
## ◆ Solutions?



# Array-based Implementation

## ◆ Circular array

- Current position is  $i$
- next position is  $(i+1)\%n$
- previous position  $(i+n-1)\%n$







# Array-based Implementation

//Enqueue function

Enqueue (x) {

if IsFull()

return

else if IsEmpty() {

front = 0

rear = 0

}

else {

rear = rear + 1

}

A[rear] = x

}

//Enqueue circular array

Enqueue (x) {

if (rear+1)%n == front

return

else if IsEmpty() {

front = 0

rear = 0

}

else {

rear = (rear + 1)%n

}

A[rear] = x

}



# Array-based Implementation

//Deque function

```
Deque () {  
    if IsEmpty()  
        print "queue empty"  
        return  
    else if front == rear {  
        // there is only one element  
        Deq=A[front]  
        front = -1  
        rear = -1  
        return Deq  
    }  
    else front = front + 1  
        return A[front-1]  
}
```

//Deque circular array

```
Deque () {  
    if IsEmpty()  
        print "queue empty"  
        return  
    else if front == rear {  
        // there is only one element  
        Deq=A[front]  
        front = -1  
        rear = -1  
        return Deq  
    }  
    else front = (front + 1)%n  
        return A[front-1]  
}
```

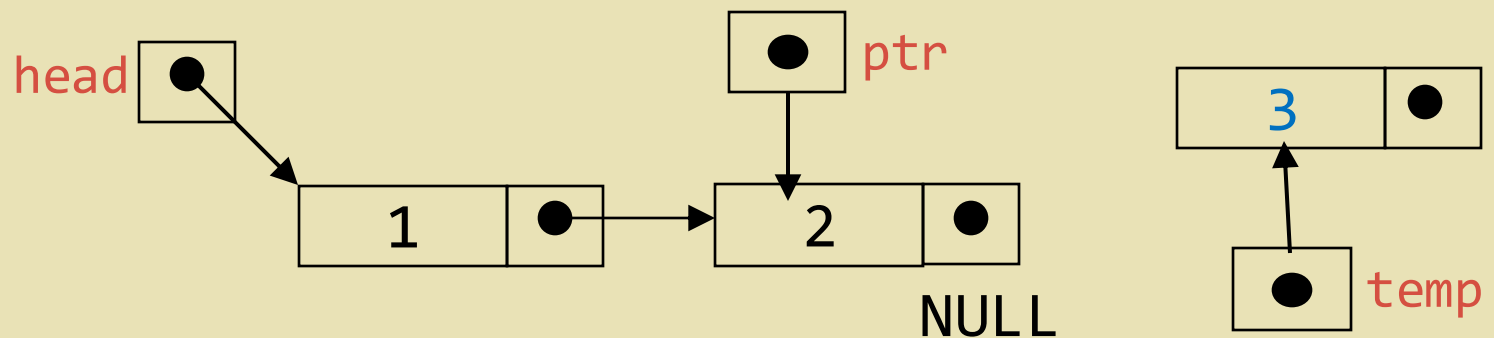


# Linked-List Implementation

- ◆ LL's head node – queue's front
- ◆ LL's tail node – queue's rear
- ◆ Enqueue – append to the end of LL
- ◆ Dequeue – remove the head node
- ◆ Recall: how did we do that in the LL?  
Time complexity?

# Inserting as a new last element

- ◆ How do we know where is the end? -- Traversal or Tail pointer

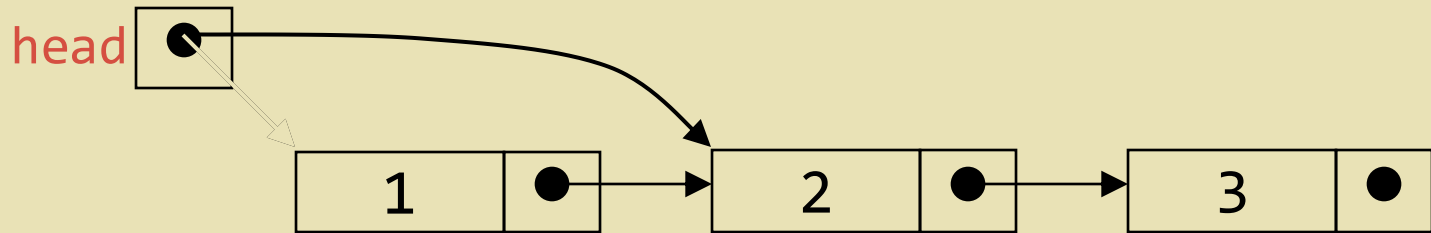



`ptr -> next = temp;`



# Deleting an element from a SLL

- To delete the first element, change the head





```
// C program for linked list implementation of Queue
```

```
#include <limits.h>
```

```
#include <stdio.h>
```

```
#include <stdlib.h>
```

```
// Node structure representing a single node in the linked list
```

```
typedef struct Node {
```

```
    int data;
```

```
    struct Node* next;
```

```
} Node;
```

```
// Function to create a new node
```

```
Node* createNode(int new_data)
```

```
{
```


```
    Node* new_node = (Node*)malloc(sizeof(Node));
```

```
    new_node->data = new_data;
```

```
    new_node->next = NULL;
```

```
    return new_node;
```

```
}
```



```
// Structure to implement queue operations using a linked list
```


```
typedef struct Queue {  
    Node *front, *rear;  
} Queue;
```

```
// Function to create a queue
```

```
Queue* createQueue() {  
    Queue* q = (Queue*)malloc(sizeof(Queue));  
    q->front = NULL;  
    q->rear = NULL;  
    return q;  
}
```

```
// Function to check if the queue is empty
```

```
int isEmpty(Queue* q)  
{  
    // If the front and rear are null, then the queue is empty, otherwise it's not  
    if (q->front == NULL && q->rear == NULL) {  
        return 1;  
    }  
    return 0;  
}
```



```
// Function to add an element to the queue
```

```
void enqueue(Queue* q, int new_data)
```

```
{
```

```
    // Create a new linked list node
```

```
    Node* new_node = createNode(new_data);
```

```
    // If queue is empty, the new node is both the front and rear
```

```
    if (q->rear == NULL)
```

```
    {
```

```
        q->front = new_node;
```

```
        q->rear = new_node;
```

```
        return;
```

```
    }
```


```
    // Add the new node at the end of the queue and change rear
```

```
    q->rear->next = new_node;
```

```
    q->rear = new_node;
```

```
}
```





// Function to remove an element from the queue

**void** dequeue(Queue\* q)

{

    // If queue is empty, return

    if (isEmpty(q))

    {

        printf("Queue Underflow\n");

**return**;

    }

    // Store previous front and move front one node ahead

    Node\* temp = q->front;

    q->front = q->front->next;

    // If front becomes null, then change rear also to null


    if (q->front == NULL)

        q->rear = NULL;

    // Deallocate memory of the old front node

    free(temp);

}



// Function to get the **front** element of  
the queue

**int** getFront(Queue\* q)

{

    // Checking if the queue is  
empty

    if (isEmpty(q))

    {

        printf("Queue is  
empty\n");

**return** INT\_MIN;

    }

**return** q->front->data;

}

// Function to get the **rear** element of  
the queue

**int** getRear(Queue\* q)

{

    // Checking if the queue is  
empty

    if (isEmpty(q))

    {

        printf("Queue is  
empty\n");

**return** INT\_MIN;

    }

**return** q->rear->data;

}



```
// Driver code
```

```
int main()
```

```
{
```

```
    Queue* q = createQueue();
```

```
    // Enqueue elements into the queue
```

```
    enqueue(q, 10);
```

```
    enqueue(q, 20);
```

```
    printf("Queue Front: %d\n", getFront(q));
```

```
    printf("Queue Rear: %d\n", getRear(q));
```

```
    // Dequeue elements from the queue
```

```
    dequeue(q);
```

```
    // Enqueue more elements into the queue
```

```
    enqueue(q, 30);
```

```
    enqueue(q, 40);
```

```
    // Dequeue an element from the queue
```

```
    dequeue(q);
```

```
    printf("Queue Front: %d\n", getFront(q));
```

```
    printf("Queue Rear: %d\n", getRear(q));
```

```
    return 0;
```

```
}
```



# More Examples on Queue Implementations

- ◆ <https://www.javatpoint.com/linked-list-implementation-of-queue>
- ◆ <https://www.scaler.com/topics/c/implementation-of-queue-using-linked-list/>
- ◆ Data structures: Array implementation of Queue (<https://www.youtube.com/watch?v=okr-XE8yTO8>) and Linked List implementation of Queue ([https://www.youtube.com/watch?v=A5\\_XdiK4J8A](https://www.youtube.com/watch?v=A5_XdiK4J8A)) by mycodeschool
- ◆ Linked list implementation of Queue in C
  - <https://gist.github.com/mycodeschool/7510222>
  - <https://gist.github.com/kroggen/5fc7380d30615b2e70fcf9c7b69997b6> (no pointer tracking the *rear*)





# Exercise

- ◆ If the head pointer is null, the queue \_\_\_\_\_.
  - A. is empty
  - B. is full
  - C. has at least one item



# Exercise

♦ If the head pointer is null, the queue \_\_\_\_\_.

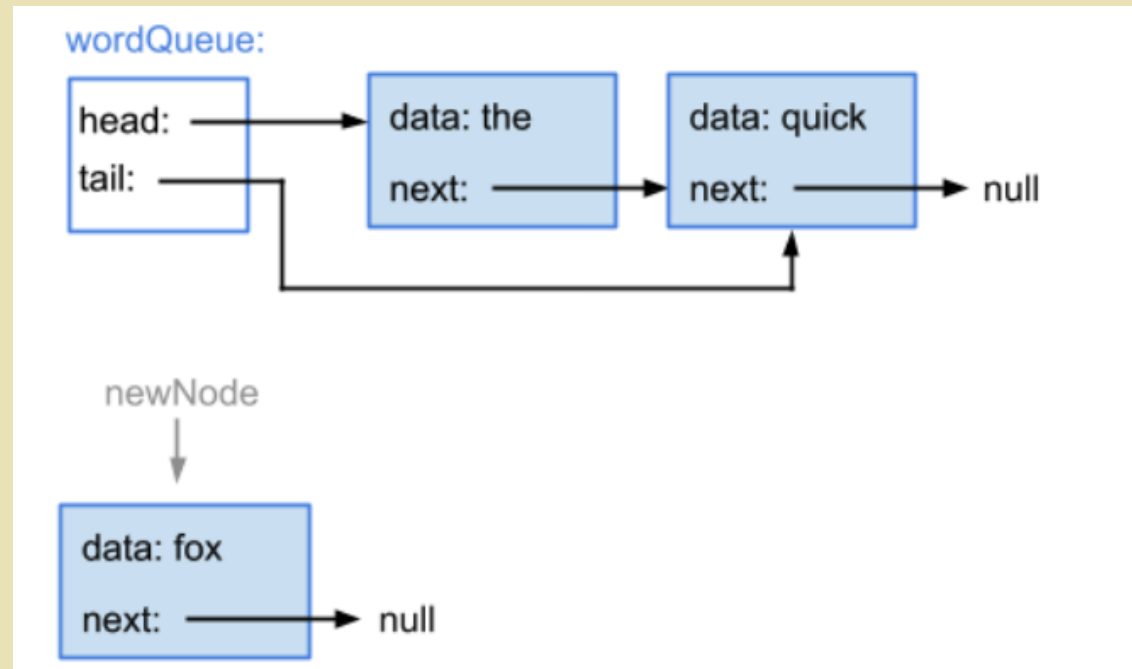
A. is empty

B. is full

C. has at least one item

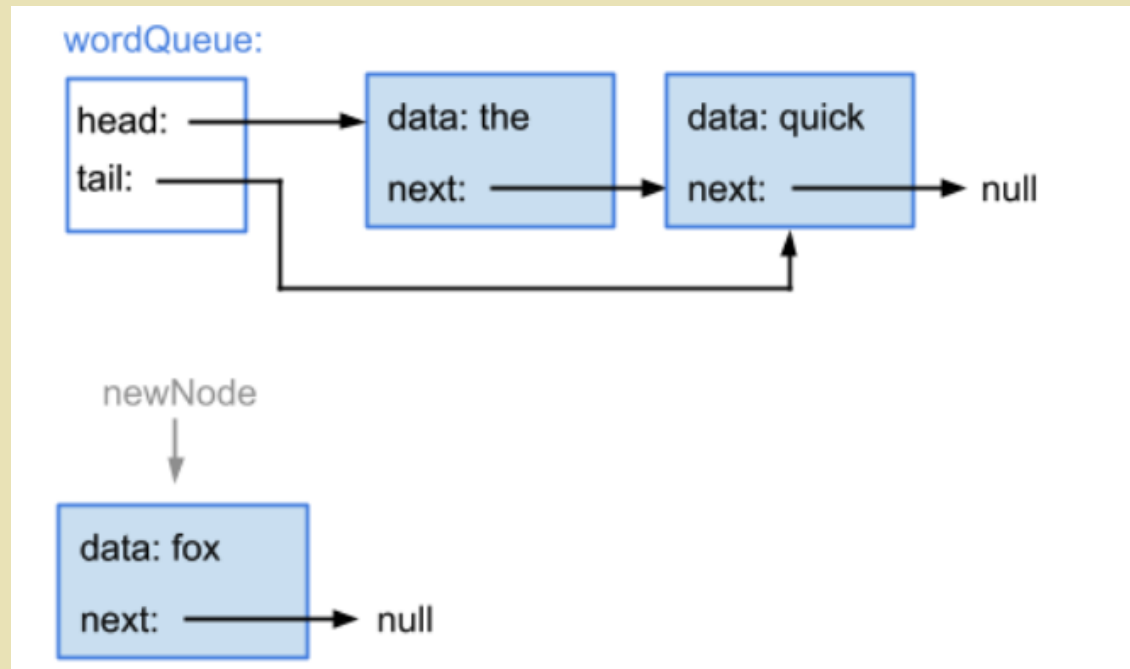
# Exercise

- ◆ For `QueueEnqueue(wordQueue, "fox")`, which pointer is updated to point to the node?



# Exercise

- ◆ For `QueueEnqueue(wordQueue, "fox")`, which pointer is updated to point to the node?



The tail node's next pointer





# References and Resources

- ◆ Course notes of ECE 250 Algorithms and Data Structures by Douglas W. Harder, University of Waterloo
- ◆ Data structures: Array implementation of Queue (<https://www.youtube.com/watch?v=okr-XE8yTO8>) and Linked List implementation of Queue ([https://www.youtube.com/watch?v=A5\\_XdiK4J8A](https://www.youtube.com/watch?v=A5_XdiK4J8A)) by mycodeschool
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That's  
about this  
lecture!

