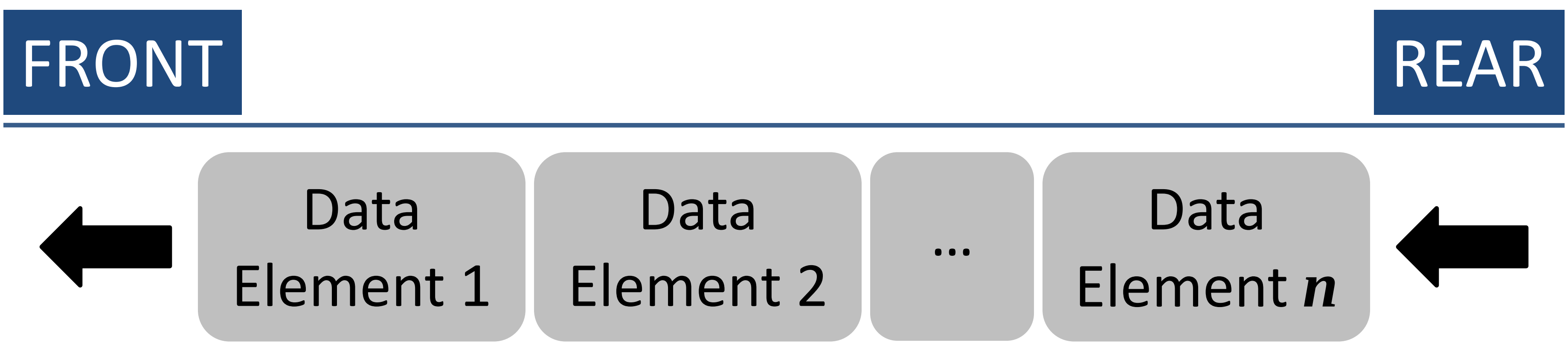
Queues

Introduction

- First in, first out (FIFO) structure (equivalent to Last in, last out (LILO) structure).
- An ordered list of homogeneous elements in which
  - Insertions take place at one end (REAR).
  - Deletions take place at the other end (FRONT).



Operations

- Two primary operations:
  - **enqueue()** – Adds an element to the ***rear*** of a queue.
  - **dequeue()** – Removes the ***front*** element of the queue.
- Other operations for effective functionality:
  - **isFull()** – Check if queue is full. ***OVERFLOW***
  - **isEmpty()** – Check if queue is empty. ***UNDERFLOW***
  - **size()** – Returns the number of elements in the queue.
  - **peek()** – Returns the element at the front of the queue.

Queue – Enqueue

enqueue(9)

front = -1

rear = -1

0	1	2	3	4

← 9

enqueue(1)

front = 0

rear = 0

9				
0	1	2	3	4

← 1

enqueue(3)

front = 0

rear = 1

9	1			
0	1	2	3	4

← 3

enqueue(6)

front = 0

rear = 2

9	1	3		
0	1	2	3	4

← 6

enqueue(4)

front = 0

rear = 3

9	1	3	6	
0	1	2	3	4

← 4

enqueue(2)

front = 0

rear = 4

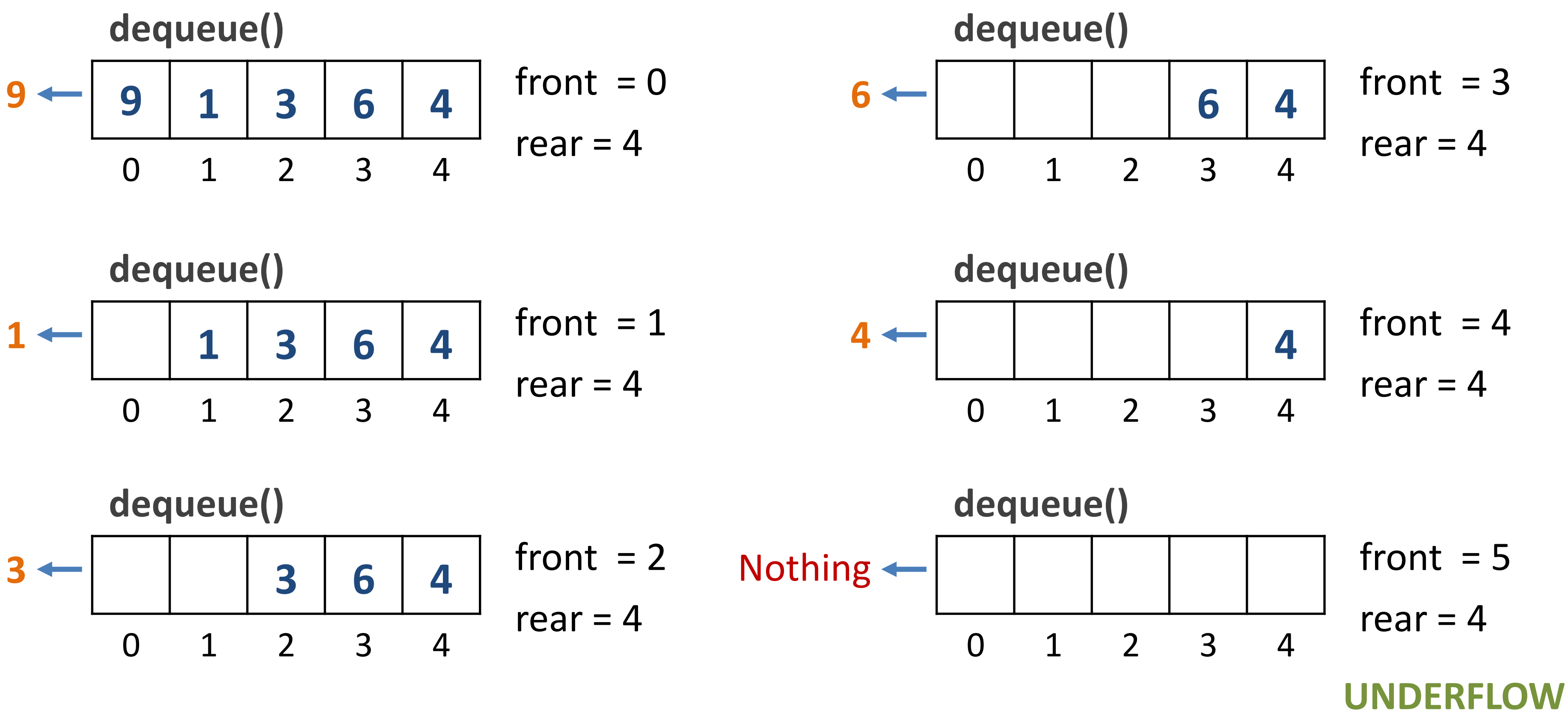
9	1	3	6	4
0	1	2	3	4

← 2

OVERFLOW

The queue is full, no more elements can be added. **OVERFLOW**

Queue – Dequeue



The queue is empty, no element can be removed. **UNDERFLOW**

Queue as an ADT

- A queue is an ordered list of elements of same data type.
- Elements are always inserted at one end (rear) and deleted from another end (front).
- Following are its basic operations:
  - ***Q = init()*** – Initialize an empty queue.
  - ***size()*** – Returns the number of elements in the queue.
  - ***isEmpty(Q)*** – Returns "true" if and only if the queue Q is empty, i.e., contains no elements.

Contd…

- ***isFull(Q)*** – Returns "true" if and only if the queue Q has a bounded size and holds the maximum number of elements it can.
- ***front(Q)*** – Returns the element at the front of the queue Q.
- ***Q = enqueue(Q,x)*** – Inserts an element x at the rear of the queue Q.
- ***Q = dequeue(Q)*** – Removes an element from the front of the queue Q.
- ***print(Q)*** – Prints the elements of the queue Q from front to rear.

Implementation

- Using static arrays
  - Realizes queues of a maximum possible size.
  - Front is maintained at the smallest index and rear at the maximum index values in the array.

- Using dynamic linked lists
  - Choose beginning of the list as the front and tail as rear of the queue.

Static Array Implementation

Enqueue Operation

- Let,
  - QUEUE be an array with N locations.
  - FRONT and REAR points to the front and rear of the QUEUE.
  - ITEM is the value to be inserted.

1. If (REAR == N – 1)
2. Print[Overflow]
3. Else
4. If (FRONT == -1 && REAR == -1)
5. Set FRONT = 0 and REAR = 0.
6. Else
7. Set REAR = REAR + 1.
8. QUEUE[REAR] = ITEM.

Dequeue Operation

- Let,
  - QUEUE be an array with N locations.
  - FRONT and REAR points to the front and rear of the QUEUE.
  - ITEM holds the value to be deleted.

1. If (FRONT == -1 || FRONT > REAR)
2. Print[Underflow]
3. Else
4. ITEM = QUEUE[FRONT]
5. Set FRONT = FRONT + 1

Static Array Implementation

```
#define MAXLEN 100

typedef struct
{   int element[MAXLEN];
    int front, rear; } queue;

queue init ()
{   queue Q;
    Q.front = Q.rear = -1;
    return Q; }

int size( queue Q )
{ return ( Q.rear – Q.front + 1 );  }

int isEmpty ( queue Q )
{    return ((Q.front == -1) ||
            (Q.front > Q.rear)); }

int isFull ( queue Q )
{   return (Q. rear == MAXLEN - 1);  }

int front ( queue Q )
{   if (isEmpty(Q))
        printf("Empty queue\n");
    else
        return Q.element[Q.front]; }
```

Contd…

```
queue enqueue ( queue Q , int x )
{     if (isFull(Q))
            printf("OVERFLOW\n");
      else if (isEmpty(Q))
      {     Q.front = Q.rear = 0;
            Q.element[Q.rear] = x;
      }
      else
      {     ++Q.rear;
            Q.element[Q.rear] = x;
      }
      return Q; }
```

```
queue dequeue ( queue Q )
{     if (isEmpty(Q))
            printf("UNDERFLOW\n");
      else
            Q.front++;
      return Q; }
```

Contd…

```
void print ( queue Q )
{       int i;
        for (i = Q.front; i <= Q.rear; i++)
            printf("%d ",Q.element[i]); }

int main ()
{   queue Q;
    Q = init();
    Q = enqueue(Q,5);
    Q = enqueue(Q,3);
    Q = dequeue(Q);
    Q = enqueue(Q,7);
    Q = dequeue(Q);
    printf("Current queue : "); print(Q);
    printf(" with front = %d.\n", front(Q));
    Q = enqueue(Q,9);
    Q = enqueue(Q,3);
    Q = enqueue(Q,1);
    printf("Current queue : "); print(Q);
    printf(" with front = %d.\n", front(Q));
    printf("Size is %d.",size(Q));
    return 0;    }
```

Dynamic Linked List Implementation

Enqueue Operation

- Let,
  - FRONT and REAR points to the front and rear of the QUEUE.
  - ITEM is the value to be inserted.

1. Create a node pointer (temp).
2. temp[data] = ITEM.
3. temp[next] = NULL.
4. If FRONT == NULL
5. FRONT = REAR = temp.
6. Else
7. REAR[next] = temp.
8. REAR = temp.

Dequeue Operation

- Let,
  - FRONT and REAR points to the front and rear of the QUEUE.
  - temp points to the element deleted from the front of the queue.

1. if (FRONT == NULL)
2. Print [Underflow]
3. else
4. Initialize a node pointer (temp) with FRONT.
5. if (FRONT == REAR)
6. FRONT = REAR = NULL
7. else
8. FRONT = FRONT[next]
9. Release the memory location pointed by temp.

Dynamic Linked List Implementation

```
struct node
{   int data;
    struct node *next, *prev;
} *front, *rear;

void init()
{   front = rear = NULL;  }
```

Contd…

```
void enqueue(int num)
{ struct node *temp = (struct node *) malloc (sizeof(struct node));
   temp -> data = num;
   if(front == NULL)
   {    temp -> prev = temp;
         temp -> next = temp;
         front = rear = temp;  }
   else
   {     temp -> prev = rear;
          rear -> next = temp;
          temp -> next = front;
         front -> prev = temp;
         rear = temp;    }         }
```

Contd…

```
void dequeue()
{   if(front == NULL)
        printf("\nQueue is empty.\n");
    else
    {   struct node *temp = front;
        if (front == rear)
            front = rear = NULL;
        else
        {   rear -> next = front -> next;
            front = front -> next;
            front -> prev = rear;    }
    free(temp);     }     }
```

Contd…

```c
void print()
{  printf("\nfront --> ");
   if (front != NULL)
   {  struct node *temp = front;
      while(temp != rear)
      {  printf("%d --> ",temp->data);
         temp = temp->next;    }
      printf("%d --> ",temp->data);
   }  printf("rear\n");
}
```

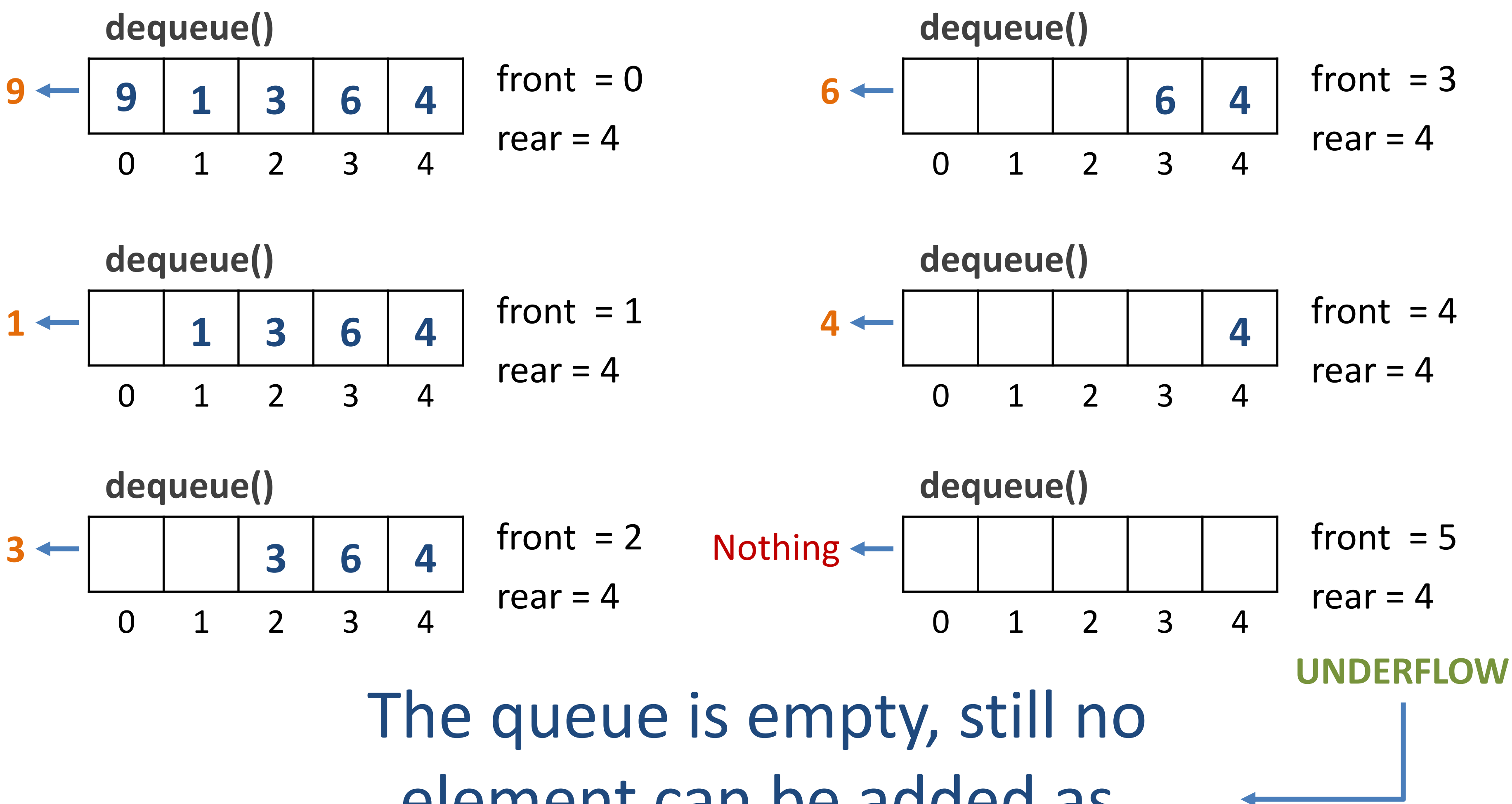
```
Current queue :
front --> 7 --> rear
Current queue :
front --> 7 --> 9 --> 3 --> 1 --> rear
```

```c
int main ()
{    init();
     enqueue(5);   enqueue(3);
     dequeue();
     enqueue(7);
     dequeue();
     printf("Current queue : ");
     print();
     enqueue(9);   enqueue(3);
     enqueue(1);
     printf("Current queue : ");
     print();
     return 0;
}
```

Queues

Variants

Problem with Simple Queues



The queue is empty, still no element can be added as **REAR = N-1** (Queue Full)

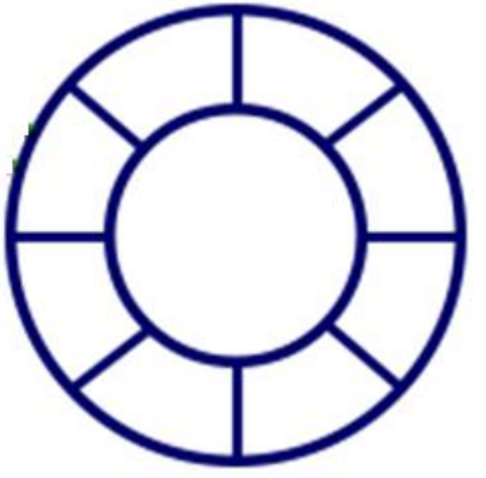
Circular Queues

- The front and rear ends of a queue are joined to make the queue circular.
- Also known as circular buffer, circular queue, cyclic buffer or ring buffer.
- Overflow full

    front == (rear+1) % MAXLEN

- Underflow empty

    (front == rear) && (rear == -1)



Contd…

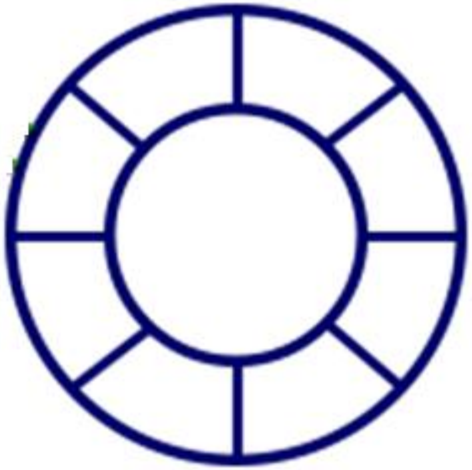
- Overflow full

    front == (rear+1) % 8

- **Underflow** empty

    (front == rear) && (rear == -1)

front = rear = -1



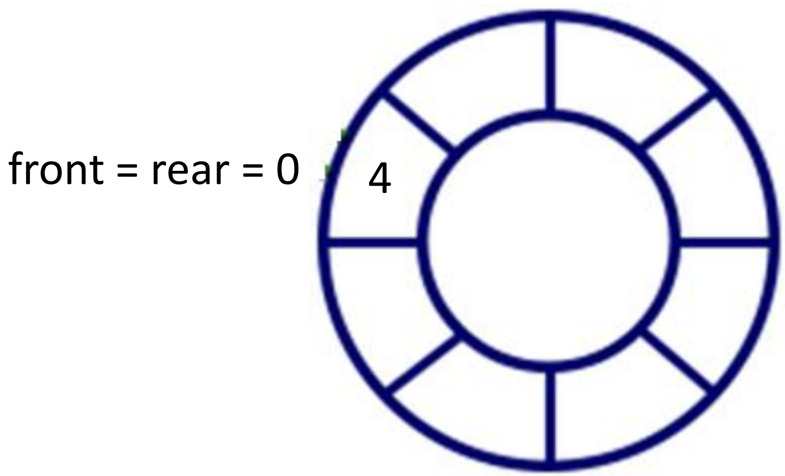
Contd…

- Overflow

    front == (rear+1) % 8

- Underflow

    (front == rear) && (rear == -1)



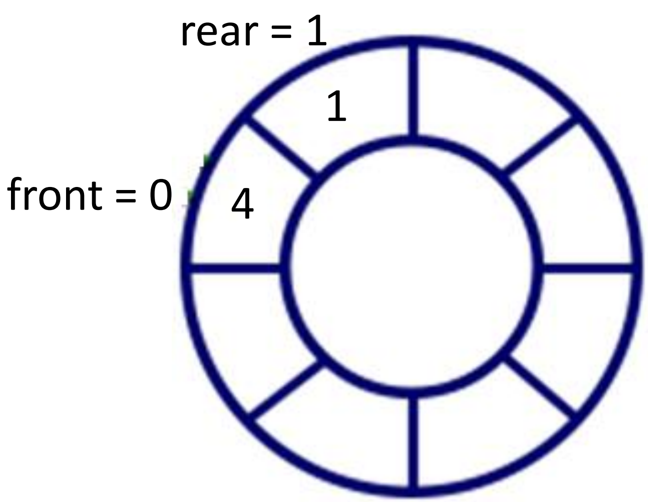
Contd…

- Overflow

    front == (rear+1) % 8

- Underflow

    (front == rear) && (rear == -1)



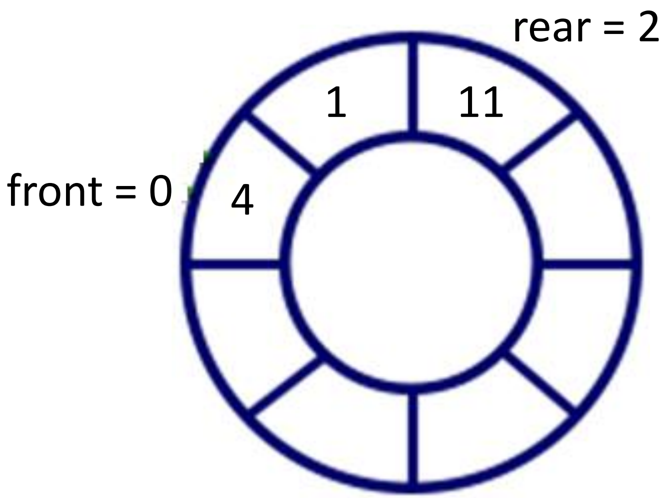
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



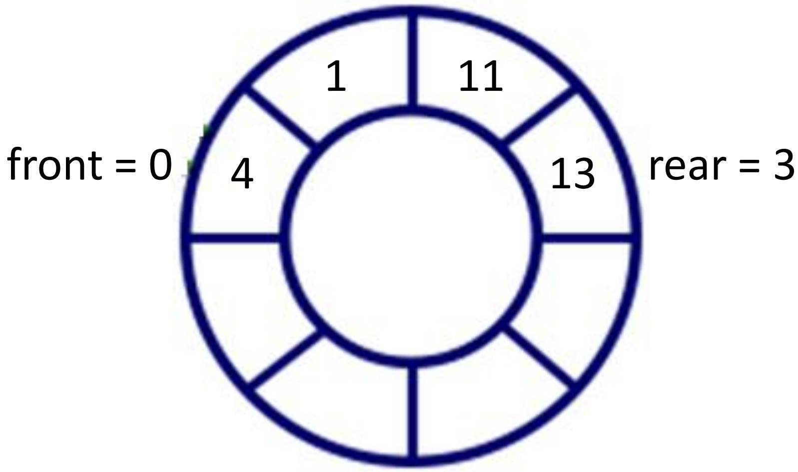
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



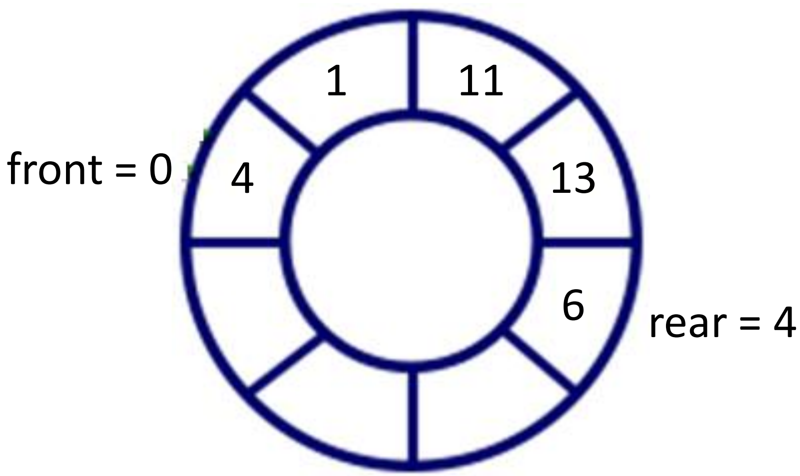
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



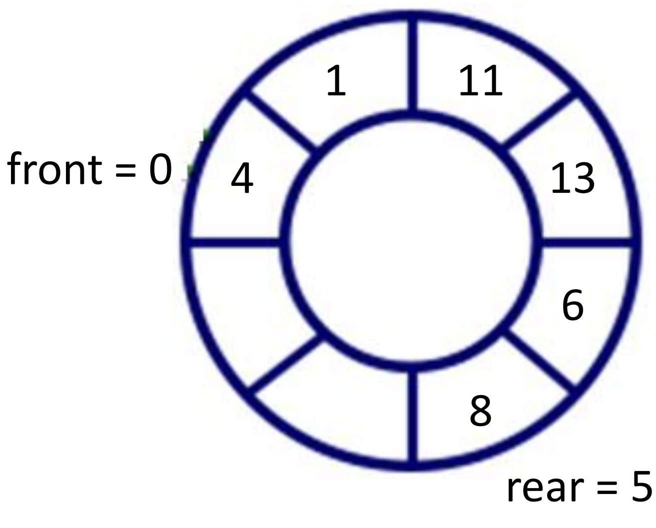
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



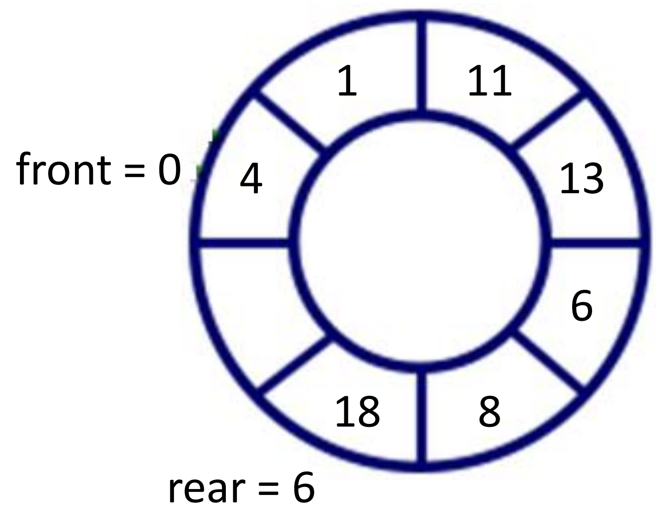
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



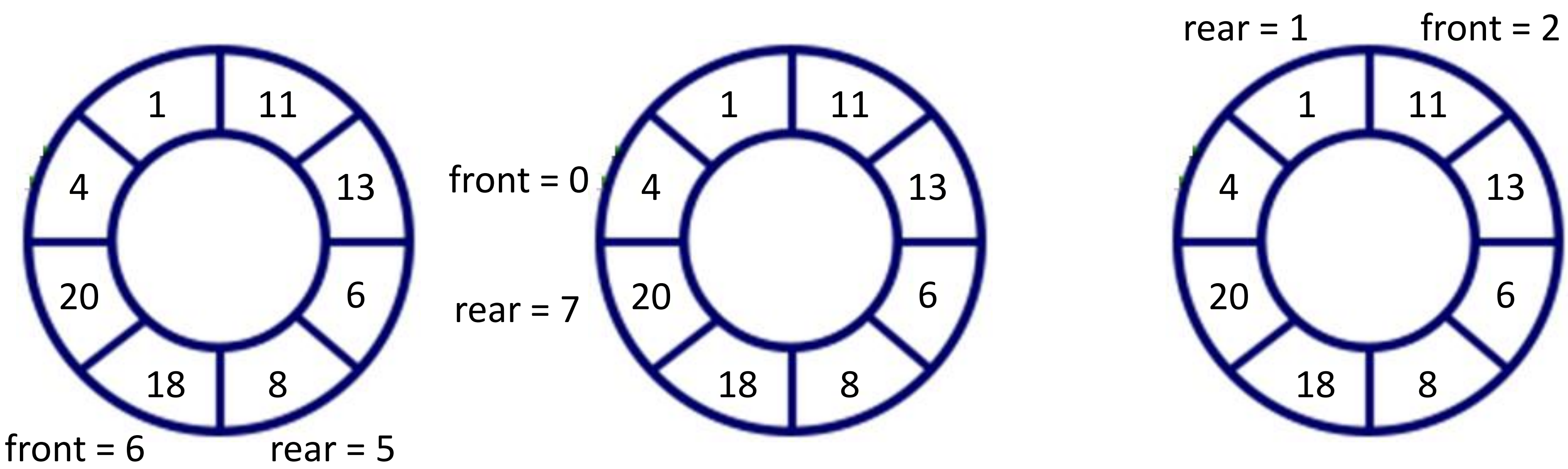
Contd…

- **Overflow**

  $front == (rear+1) \% 8$

- Underflow

  $(front == rear) \&\& (rear == -1)$



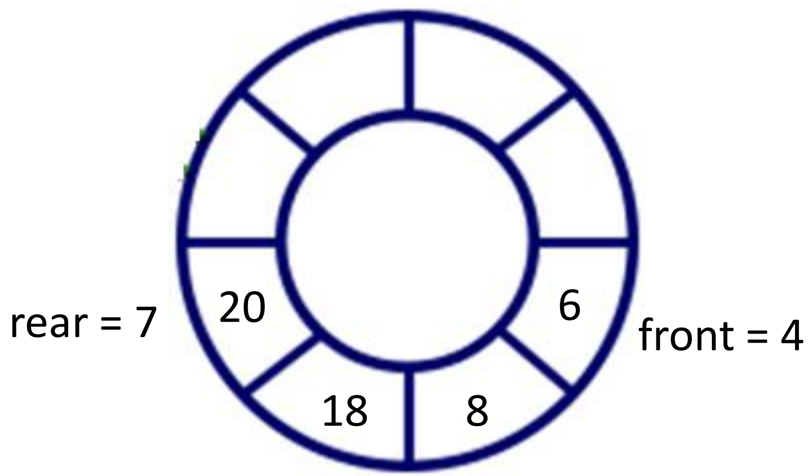
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



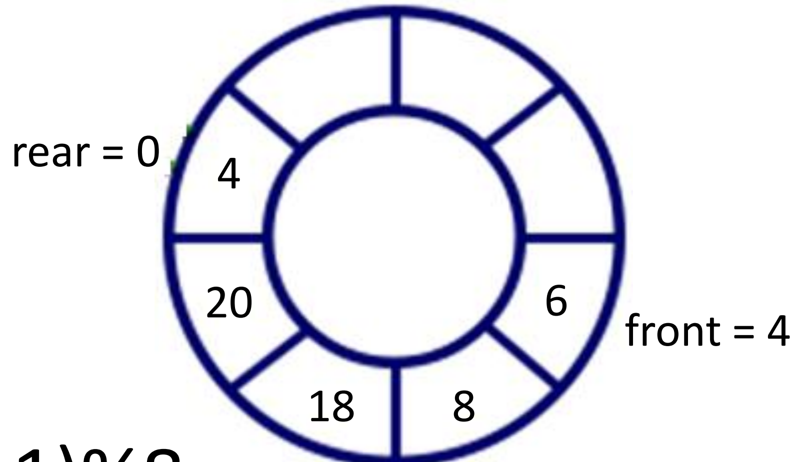
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



REAR = (REAR+1)%8

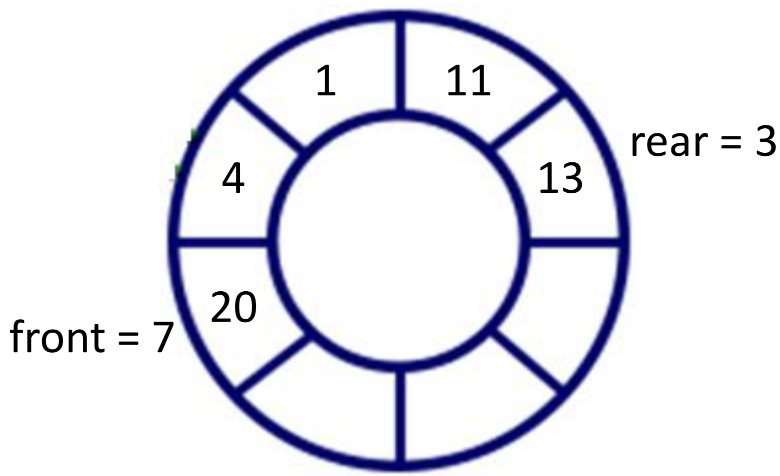
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



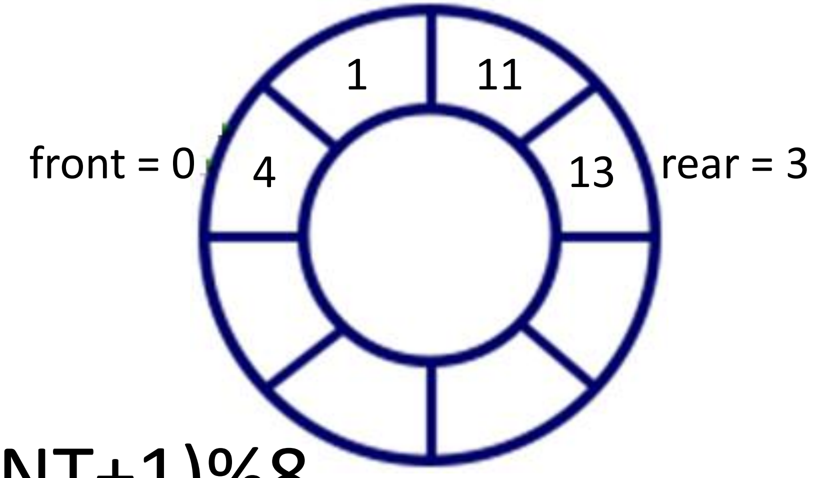
Contd…

- Overflow

  front == (rear+1) % 8

- Underflow

  (front == rear) && (rear == -1)



FRONT = (FRONT+1)%8

Enqueue Operation

- Let,
  - QUEUE be an array with MAX locations.
  - FRONT and REAR points to the front and rear of the QUEUE.
  - ITEM is the value to be inserted.

1. if (FRONT == (REAR+1)%MAX)
2. Print [Overflow]
3. else
4. Set REAR = (REAR+1)%MAX
5. Set QUEUE[REAR] = element
6. If (FRONT == -1)
7. Set FRONT = 0

Dequeue Operation

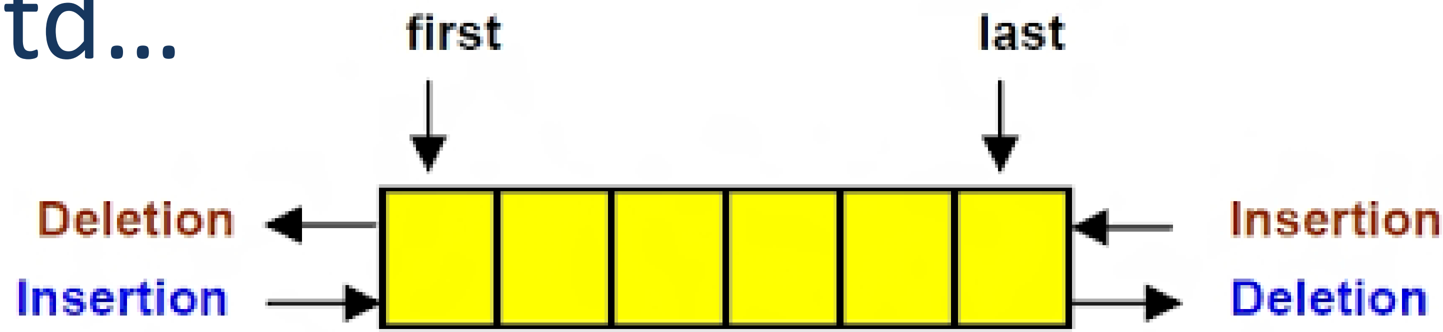
- Let,
  - QUEUE be an array with MAX locations.
  - FRONT and REAR points to the front and rear of the QUEUE.
  - ITEM holds the value to be deleted.

1. if ((FRONT == REAR) && (REAR == -1))
2. Print [Underflow]
3. else
4. ITEM = Q[FRONT]
5. If (FRONT == REAR)
6. FRONT = REAR = -1
7. Else
8. FRONT = (FRONT + 1) % MAX

Deque

- **D**ouble-**e**nded **que**ue.
- Generalization of queue data structure.
- Elements can be added to or removed from either of the two ends.
- A hybrid linear structure that provides all the capabilities of stacks and queues in a single data structure.
- Does not require the LIFO and FIFO orderings.

Contd…



Types

- Input-restricted deque.
  - Deletion can be made from both ends, but insertion can be made at one end only.
- Output-restricted deque.
  - Insertion can be made at both ends, but deletion can be made from one end only.

Priority Queues

- Another variant of queue data structure.
- Each element has an associated priority.
- Insertion may be performed based on the priority.
- Deletion is performed based on the priority.
- Elements having the same priority are served or deleted according to first come first serve order.
- Two types:
  - Min-priority queues (Ascending priority queues)
  - Max-priority queues (Descending priority queues)

Implementation

- Array representation: Unordered and Ordered
- Linked-list representations: Unordered and Ordered
- Unordered does not consider priority during insertion, instead insertion takes place at the end.
- Ordered considers priority during insertion and inserts an element at correct place as per min or max priority.
- Note
  - Either insertion or deletion take linear time in the worst case.
  - Priority queues are often implemented with heaps.

Example

Element to be deleted is replaced with the last array element.

Operation	Argument	Return Value	Size	Contents	
				Unordered	Ordered (Ascending)
Insert	P		1	**P**	**P**
Insert	Q		2	P **Q**	P **Q**
Insert	E		3	P Q **E**	**E** P Q
Remove MAX		**Q**	2	P E	E P
Insert	X		3	P E **X**	E P **X**
Insert	A		4	P E X **A**	**A** E P X
Insert	M		5	P E X A **M**	A E **M** P X
Remove MIN		**A**	4	P E X M	E M P X