QUEUE

1. A queue can be defined as an ordered list which enables insert operations to be performed at one end called REAR and delete operations to be performed at another end called FRONT.

2. Queue is referred to be as First In First Out(FIFO) list.

3. For example, people waiting in line for a rail ticket form a queue.

Applications of Queue

Due to the fact that queue performs actions on first in first out basis which is quite fair for the ordering of actions. There are various applications of queues discussed as below.

1. Queues are widely used as waiting lists for a single shared resource like printer, disk, CPU.
2. Queues are used in asynchronous transfer of data (where data is not being transferred at the same rate between two processes) for eg. pipes, file IO, sockets.
3. Queues are used as buffers in most of the applications like MP3 media player, CD player, etc.
4. Queue are used to maintain the play list in media players in order to add and remove the songs from the play-list.
5. Queues are used in operating systems for handling interrupts.

Complexity

Data Structure	Time Complexity								Space Compleity
	Average				Worst				Worst
	Access	Search	Insertion	Deletion	Access	Search	Insertion	Deletion	
Queue	θ(n)	θ(n)	θ(1)	θ(1)	O(n)	O(n)	O(1)	O(1)	O(n)

What is the Queue?

A queue in the data structure can be considered similar to the queue in the real-world. A queue is a data structure in which whatever comes first will go out first. It follows the FIFO (First-In-First-Out) policy. In Queue, the insertion is done from one end known as the rear end or the tail of the queue, whereas the deletion is done from another end known as the front end or the head of the queue. In other words, it can be defined as a list or a collection with a constraint that the insertion can be performed at one end called as the rear end or tail of the queue and deletion is performed on another end called as the front end or the head of the queue.

Type of Queues

Operations on Queue

There are two fundamental operations performed on a Queue:

1. **Enqueue:** The enqueue operation is used to insert the element at the rear end of the queue. It returns void.
2. **Dequeue:** The dequeue operation performs the deletion from the front-end of the queue. It also returns the element which has been removed from the front-end. It returns an integer value. The dequeue operation can also be designed to void.
3. **Peek:** This is the third operation that returns the element, which is pointed by the front pointer in the queue but does not delete it.
4. **Queue overflow (isfull):** When the Queue is completely full, then it shows the overflow condition.
5. **Queue underflow (isempty):** When the Queue is empty, i.e., no elements are in the Queue then it throws the underflow condition.

Implementation of Queue

There are two ways of implementing the Queue:

- **Sequential allocation**: The sequential allocation in a Queue can be implemented using an **array**.
- **Linked list allocation**: The linked list allocation in a Queue can be implemented using a **linked list**.

What are the use cases of Queue?

Here, we will see the real-world scenarios where we can use the Queue data structure. The Queue data structure is mainly used where there is a shared resource that has to serve the multiple requests but can serve a single request at a time. In such cases, we need to use the Queue data structure for queuing up the requests. The request that arrives first in the queue will be served first. The following are the real-world scenarios in which the Queue concept is used:

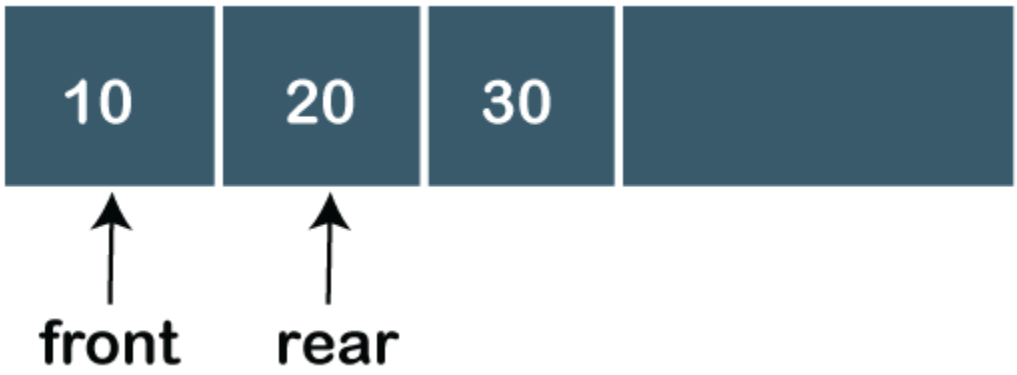
- Suppose we have a printer shared between various machines in a network, and any machine or computer in a network can send a print request to the printer. But, the printer can serve a single request at a time, i.e., a printer can print a single document at a time. When any print request comes from the network, and if the printer is busy, the printer's program will put the print request in a queue.
- . If the requests are available in the Queue, the printer takes a request from the front of the queue, and serves it.
- The processor in a computer is also used as a shared resource. There are multiple requests that the processor must execute, but the processor can serve a single request or execute a single process at a time. Therefore, the processes are kept in a Queue for execution.

Types of Queue

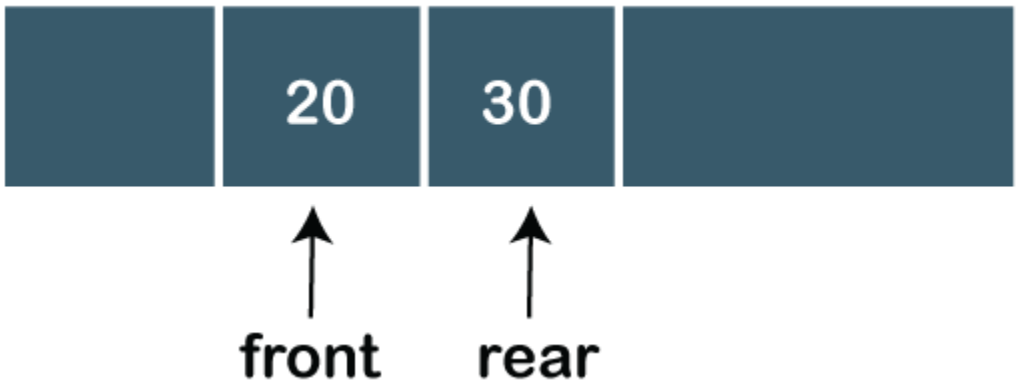
There are four types of Queues:

- **Linear Queue**

In Linear Queue, an insertion takes place from one end while the deletion occurs from another end. The end at which the insertion takes place is known as the rear end, and the end at which the deletion takes place is known as front end. It strictly follows the FIFO rule. The linear Queue can be represented, as shown in the below figure:



The above figure shows that the elements are inserted from the rear end, and if we insert more elements in a Queue, then the rear value gets incremented on every insertion. If we want to show the deletion, then it can be represented as:

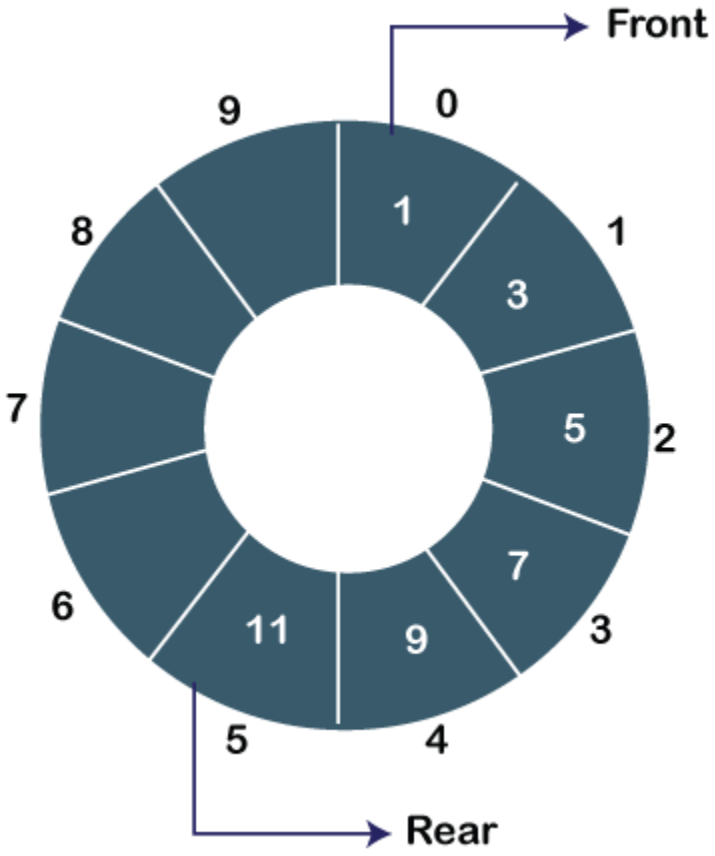


In the above figure, we can observe that the front pointer points to the next element, and the element which was previously pointed by the front pointer was deleted.

The major drawback of using a **linear Queue** is that insertion is done only from the rear end. If the first three elements are deleted from the Queue, we cannot insert more elements even though the space is available in a Linear Queue. In this case, the linear Queue shows the **overflow** condition as the rear is pointing to the last element of the Queue.

- **Circular Queue**

In Circular Queue, all the nodes are represented as circular. It is similar to the linear Queue except that the last element of the queue is connected to the first element. It is also known as **Ring Buffer** as all the ends are connected to another end. The circular queue can be represented as:



The drawback that occurs in a linear queue is overcome by using the circular queue. If the empty space is available in a circular queue, the new element can be added in an empty space by simply incrementing the value of rear.

To know more about circular queue,

- **Priority Queue**

A priority queue is another special type of Queue data structure in which each element has some priority associated with it. Based on the priority of the element, the elements are arranged in a priority queue. If the elements occur with the same priority, then they are served according to the FIFO principle.

In priority Queue, the insertion takes place based on the arrival while the deletion occurs based on the priority. The priority Queue can be shown as:

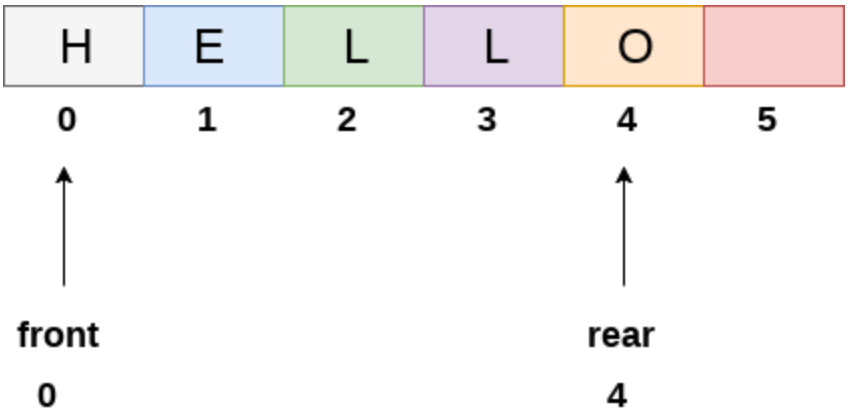
The above figure shows that the highest priority element comes first and the elements of the same priority are arranged based on FIFO structure.

- **Deque**

Both the Linear Queue and Deque are different as the linear queue follows the FIFO principle whereas, deque does not follow the FIFO principle. In Deque, the insertion and deletion can occur from both ends.

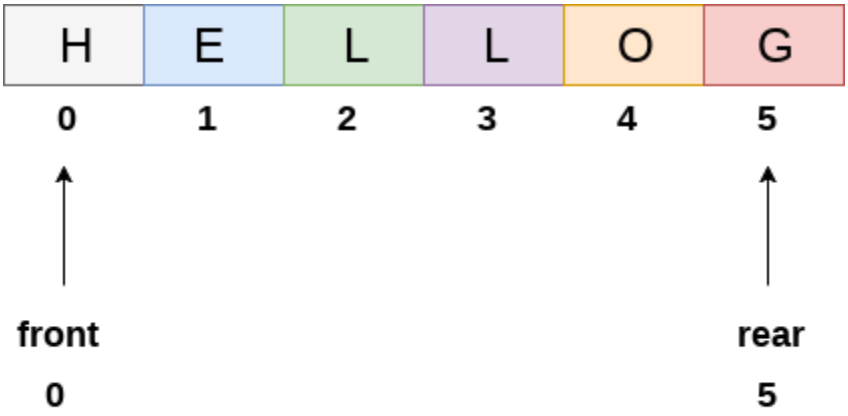
Array representation of Queue

We can easily represent queue by using linear arrays. There are two variables i.e. front and rear, that are implemented in the case of every queue. Front and rear variables point to the position from where insertions and deletions are performed in a queue. Initially, the value of front and queue is -1 which represents an empty queue. Array representation of a queue containing 5 elements along with the respective values of front and rear, is shown in the following figure.



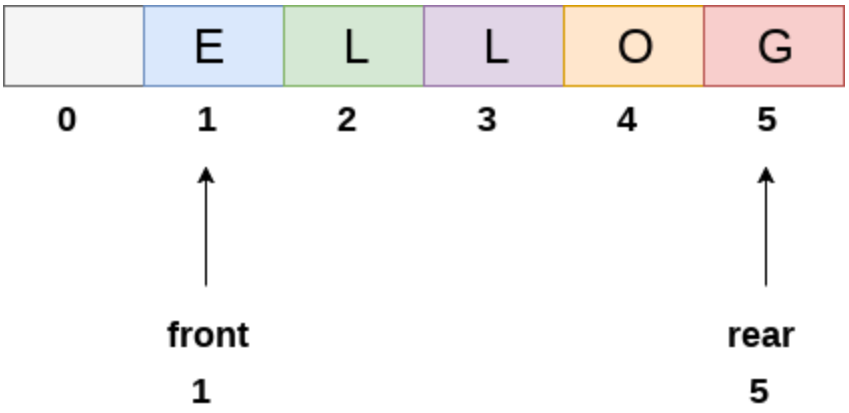
Queue

The above figure shows the queue of characters forming the English word **"HELLO"**. Since, No deletion is performed in the queue till now, therefore the value of front remains -1 . However, the value of rear increases by one every time an insertion is performed in the queue. After inserting an element into the queue shown in the above figure, the queue will look something like following. The value of rear will become 5 while the value of front remains same.



Queue after inserting an element

After deleting an element, the value of front will increase from -1 to 0. however, the queue will look something like following.



Queue after deleting an element

Algorithm to insert any element in a queue

Check if the queue is already full by comparing rear to max - 1. if so, then return an overflow error.

If the item is to be inserted as the first element in the list, in that case set the value of front and rear to 0 and insert the element at the rear end.

Otherwise keep increasing the value of rear and insert each element one by one having rear as the index.

Algorithm

- **Step 1:** IF REAR = MAX - 1
  Write OVERFLOW
  Go to step
  [END OF IF]
- **Step 2:** IF FRONT = -1 and REAR = -1
  SET FRONT = REAR = 0
  ELSE
  SET REAR = REAR + 1
  [END OF IF]
- **Step 3:** Set QUEUE[REAR] = NUM
- **Step 4:** EXIT

C Function

```
void insert (int queue[], int max, int front, int rear, int item)
{
   if (rear + 1 == max)
   {
      printf("overflow");
   }
   else
   {
      if(front == -1 && rear == -1)
      {
         front = 0;
         rear = 0;
      }
      else
      {
         rear = rear + 1;
      }
      queue[rear]=item;
   }
}
```

Algorithm to delete an element from the queue

If, the value of front is -1 or value of front is greater than rear , write an underflow message and exit.

Otherwise, keep increasing the value of front and return the item stored at the front end of the queue at each time.

Algorithm

- **Step 1:** IF FRONT = -1 or FRONT > REAR
  Write UNDERFLOW
  ELSE
  SET VAL = QUEUE[FRONT]
  SET FRONT = FRONT + 1
  [END OF IF]
- **Step 2:** EXIT

display

Algorithm

Step 1: IF REAR == -1

- Write UNDERFLOW/empty
- ELSE
- FOR(I SET VAL = QUEUE[FRONT]; SET VAL <= QUEUE[REAR]; I++)

  QUEUE[I]

- [END OF IF]

Step 2: EXIT

C Function

```
int delete (int queue[], int max, int front, int rear)
{
   int y;
```

```
    if (front == -1 || front > rear)


    {
        printf("underflow");
    }
    else
    {
        y = queue[front];
        if(front == rear)
        {
            front = rear = -1;
            else
            front = front + 1;


        }
        return y;
    }
}
```

All in one Menu driven program to implement queue using array

```
#include<stdio.h>
#include<stdlib.h>
#define maxsize 5
void insert();
void delete();
void display();
int front = -1, rear = -1;
int queue[maxsize];
void main ()
{
   int choice;
   while(choice != 4)
   {
      printf("\n*************************Main Menu*****************************\n");
      printf("\n===================================================================\n");
      printf("\n1.insert an element\n2.Delete an element\n3.Display the queue\n4.Exit\n");
      printf("\nEnter your choice ?");
      scanf("%d",&choice);
      switch(choice)
      {
         case 1:
         insert();
         break;
         case 2:
```

```
            delete();
            break;
            case 3:
            display();
            break;
            case 4:
            exit(0);
            break;
            default:
            printf("\nEnter valid choice??\n");
        }
    }
}
void insert()
{
    int item;
    printf("\nEnter the element\n");
    scanf("\n%d",&item);
    if(rear == maxsize-1)
    {
        printf("\nOVERFLOW\n");
        return;
    }
    if(front == -1 && rear == -1)
    {
        front = 0;
        rear = 0;
    }
    else
```

```
    {
        rear = rear+1;
    }
    queue[rear] = item;
    printf("\nValue inserted ");

}
void delete()
{
    int item;
    if (front == -1 || front > rear)
    {
        printf("\nUNDERFLOW\n");
        return;

    }
    else
    {
        item = queue[front];
        if(front == rear)
        {
            front = -1;
            rear = -1 ;
        }
        else
        {
            front = front + 1;
        }
        printf("\nvalue deleted ");
```

```
    }



}

void display()
{
    int i;
    if(rear == -1)
    {
        printf("\nEmpty queue\n");
    }
    else
    {   printf("\nprinting values .....\n");
        for(i=front;i<=rear;i++)
        {
            printf("\n%d\n",queue[i]);
        }
    }
}
```

Linked List implementation of Queue

Due to the drawbacks discussed in the previous section of this tutorial, the array implementation can not be used for the large scale applications where the queues are implemented. One of the alternative of array implementation is linked list implementation of queue.

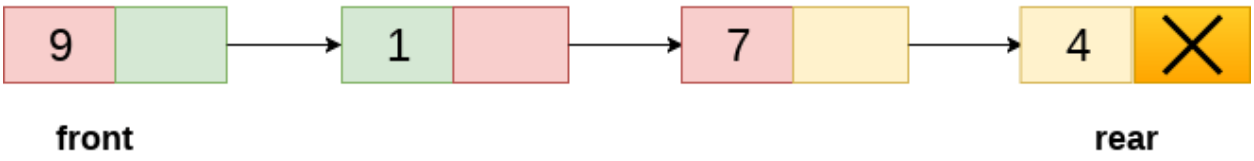
The storage requirement of linked representation of a queue with n elements is o(n) while the time requirement for operations is o(1).

In a linked queue, each node of the queue consists of two parts i.e. data part and the link part. Each element of the queue points to its immediate next element in the memory.

In the linked queue, there are two pointers maintained in the memory i.e. front pointer and rear pointer. The front pointer contains the address of the starting element of the queue while the rear pointer contains the address of the last element of the queue.

Insertion and deletions are performed at rear and front end respectively. If front and rear both are NULL, it indicates that the queue is empty.

The linked representation of queue is shown in the following figure.



Linked Queue

Operation on Linked Queue

There are two basic operations which can be implemented on the linked queues. The operations are Insertion and Deletion.

Insert operation

The insert operation append the queue by adding an element to the end of the queue. The new element will be the last element of the queue.

Firstly, allocate the memory for the new node ptr by using the following statement.

*Ptr = (struct node *) malloc (sizeof(struct node));*

There can be the two scenario of inserting this new node ptr into the linked queue.

In the first scenario, we insert element into an empty queue. In this case, the condition front = NULL becomes true. Now, the new element will be added as the only element of the queue and the next pointer of front and rear pointer both, will point to NULL.

```
ptr -> data = item;
    if(front == NULL)
    {
       front = ptr;
       rear = ptr;
       front -> next = NULL;
       rear -> next = NULL;
    }
```

In the second case, the queue contains more than one element. The condition front = NULL becomes false. In this scenario, we need to update the end pointer rear so that the next pointer of rear will point to the new node ptr. Since, this is a linked queue, hence we also need to make the rear pointer point to the newly added node ptr. We also need to make the next pointer of rear point to NULL.

rear -> next = ptr;

rear = ptr;

rear->next = NULL;

In this way, the element is inserted into the queue. The algorithm and the C implementation is given as follows.

Algorithm

- **Step 1:** Allocate the space for the new node PTR
- **Step 2:** SET PTR -> DATA = VAL
- **Step 3:** IF FRONT = NULL
  SET FRONT = REAR = PTR
  SET FRONT -> NEXT = REAR -> NEXT = NULL
  ELSE
  SET REAR -> NEXT = PTR
  SET REAR = PTR
  SET REAR -> NEXT = NULL
  [END OF IF]
- **Step 4:** END

C Function

```
void insert(struct node *ptr, int item; )
{

   ptr = (struct node *) malloc (sizeof(struct node));
   if(ptr == NULL)
   {
      printf("\nOVERFLOW\n");
      return;
```

```
    }
    else
    {
        ptr -> data = item;
        if(front == NULL)
        {
            front = ptr;
            rear = ptr;
            front -> next = NULL;
            rear -> next = NULL;
        }
        else
        {
            rear -> next = ptr;
            rear = ptr;
            rear->next = NULL;
        }
    }
}
```

Deletion

Deletion operation removes the element that is first inserted among all the queue elements. Firstly, we need to check either the list is empty or not. The condition front == NULL becomes true if the list is empty, in this case , we simply write underflow on the console and make exit.

Otherwise, we will delete the element that is pointed by the pointer front. For this purpose, copy the node pointed by the front pointer into the pointer ptr. Now, shift the front pointer, point to its next node and free the node pointed by the node ptr. This is done by using the following statements.

```
ptr = front;
    front = front -> next;
    free(ptr);
```

The algorithm and C function is given as follows.

Algorithm

- **Step 1:** IF FRONT = NULL
  Write " Underflow "
  Go to Step 5
  [END OF IF]
- **Step 2:** SET PTR = FRONT
- **Step 3:** SET FRONT = FRONT -> NEXT
- **Step 4:** FREE PTR
- **Step 5:** END

C Function

```
void delete (struct node *ptr)
{
  if(front == NULL)
  {
     printf("\nUNDERFLOW\n");
```

```
        return;
    }
    else
    {
        ptr = front;
        front = front -> next;
        free(ptr);
    }
}
```

All in one menu-Driven Program implementing all the operations on Linked Queue

```
#include<stdio.h>
#include<stdlib.h>
struct node
{
   int data;
   struct node *next;
};
struct node *front;
struct node *rear;
void insert();
void delete();
void display();
void main ()
{
   int choice;
   while(choice != 4)
   {
      printf("\n*************************Main Menu*****************************\n");
      printf("\n===================================================================\n");
      printf("\n1.insert an element\n2.Delete an element\n3.Display the queue\n4.Exit\n");
      printf("\nEnter your choice ?");
      scanf("%d",& choice);
      switch(choice)
      {
         case 1:
         insert();
         break;
         case 2:
```

```
            delete();
            break;
            case 3:
            display();
            break;
            case 4:
            exit(0);
            break;
            default:
            printf("\nEnter valid choice??\n");
        }
    }
}
void insert()
{
    struct node *ptr;
    int item;

    ptr = (struct node *) malloc (sizeof(struct node));
    if(ptr == NULL)
    {
        printf("\nOVERFLOW\n");
        return;
    }
    else
    {
        printf("\nEnter value?\n");
        scanf("%d",&item);
        ptr -> data = item;
```

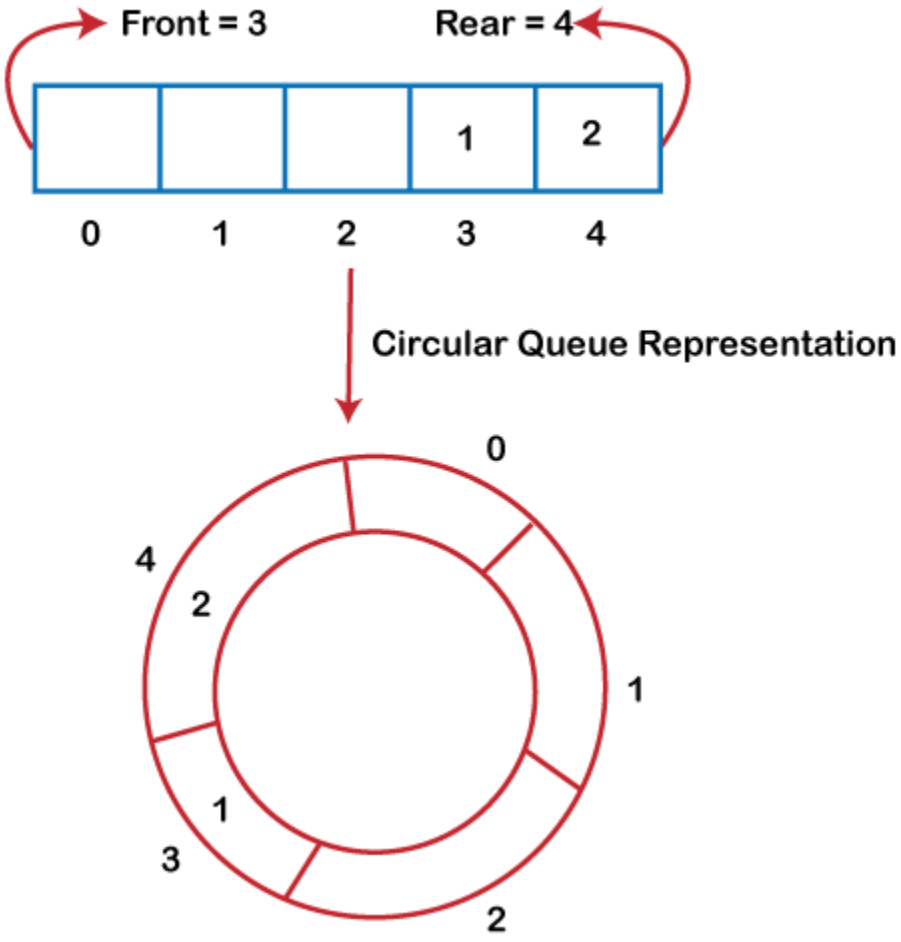
```
        if(front == NULL)
        {
            front = ptr;
            rear = ptr;
            front -> next = NULL;
            rear -> next = NULL;
        }
        else
        {
            rear -> next = ptr;
            rear = ptr;
            rear->next = NULL;
        }
    }
}
void delete ()
{
    struct node *ptr;
    if(front == NULL)
    {
        printf("\nUNDERFLOW\n");
        return;
    }
    else
    {
        ptr = front;
        front = front -> next;
        free(ptr);
    }
```

```
}
void display()
{
   struct node *ptr;
   ptr = front;
   if(front == NULL)
   {
      printf("\nEmpty queue\n");
   }
   else
   {   printf("\nprinting values .....\n");
      while(ptr != NULL)
      {
         printf("\n%d\n",ptr -> data);
         ptr = ptr -> next;
      }
   }
}
```

Circular Queue

Why was the concept of the circular queue introduced?

There was one limitation in the array implementation of Queue. If the rear reaches to the end position of the Queue then there might be possibility that some vacant spaces are left in the beginning which cannot be utilized. So, to overcome such limitations, the concept of the circular queue was introduced.



As we can see in the above image, the rear is at the last position of the Queue and front is pointing somewhere rather than the 0^{th} position. In the above array, there are only two elements and other three positions are empty. The rear is at the last position of the Queue; if we try to insert the element then it will show that there are no empty spaces in the Queue. There is one solution to avoid such wastage of memory space by shifting both the

elements at the left and adjust the front and rear end accordingly. It is not a practically good approach because shifting all the elements will consume lots of time. The efficient approach to avoid the wastage of the memory is to use the circular queue data structure.

What is a Circular Queue?

A circular queue is similar to a linear queue as it is also based on the FIFO (First In First Out) principle except that the last position is connected to the first position in a circular queue that forms a circle. It is also known as a ***Ring Buffer***.

Operations on Circular Queue

The following are the operations that can be performed on a circular queue:

- **Front:** It is used to get the front element from the Queue.
- **Rear:** It is used to get the rear element from the Queue.
- **enQueue(value):** This function is used to insert the new value in the Queue. The new element is always inserted from the rear end.
- **deQueue():** This function deletes an element from the Queue. The deletion in a Queue always takes place from the front end.

Applications of Circular Queue

The circular Queue can be used in the following scenarios:

- **Memory management:** The circular queue provides memory management. As we have already seen that in linear queue, the memory is not managed very efficiently. But in case of a circular queue, the memory is managed efficiently by placing the elements in a location which is unused.
- **CPU Scheduling:** The operating system also uses the circular queue to insert the processes and then execute them.
- **Traffic system:** In a computer-control traffic system, traffic light is one of the best examples of the circular queue. Each light of traffic light gets ON one by one after every jinterval of time. Like red light gets ON for one minute then yellow light for one minute and then green light. After green light, the red light gets ON.

Enqueue operation

The steps of enqueue operation are given below:

- First, we will check whether the Queue is full or not.
- Initially the front and rear are set to -1. When we insert the first element in a Queue, front and rear both are set to 0.
- When we insert a new element, the rear gets incremented, i.e., ***rear=rear+1***.

Scenarios for inserting an element

There are two scenarios in which queue is not full:

- **If rear != max - 1**, then rear will be incremented to **mod(maxsize)** and the new value will be inserted at the rear end of the queue.
- **If front != 0 and rear = max - 1**, it means that queue is not full, then set the value of rear to 0 and insert the new element there.

There are two cases in which the element cannot be inserted:

- When **front ==0** && **rear = max-1**, which means that front is at the first position of the Queue and rear is at the last position of the Queue.
- front== rear + 1;

Algorithm to insert an element in a circular queue

Step 1: IF (REAR+1)%MAX = FRONT
Write " OVERFLOW "
Goto step 4
[End OF IF]

Step 2: IF FRONT = -1 and REAR = -1
SET FRONT = REAR = 0
ELSE IF REAR = MAX - 1 and FRONT ! = 0
SET REAR = 0
ELSE

SET REAR = (REAR + 1) % MAX
[END OF IF]

Step 3: SET QUEUE[REAR] = VAL

Step 4: EXIT

Dequeue Operation

The steps of dequeue operation are given below:

- First, we check whether the Queue is empty or not. If the queue is empty, we cannot perform the dequeue operation.
- When the element is deleted, the value of front gets decremented by 1.
- If there is only one element left which is to be deleted, then the front and rear are reset to -1.

Algorithm to delete an element from the circular queue

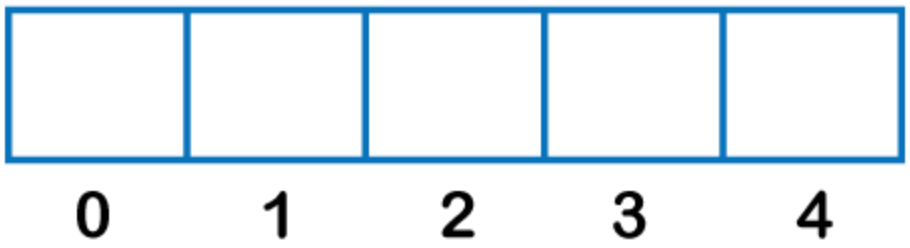
Step 1: IF FRONT = -1
Write " UNDERFLOW "
Goto Step 4
[END of IF]

Step 2: SET VAL = QUEUE[FRONT]

Step 3: IF FRONT = REAR
SET FRONT = REAR = -1
ELSE
IF FRONT = MAX -1
SET FRONT = 0
ELSE
SET FRONT = FRONT + 1
[END of IF]
[END OF IF]

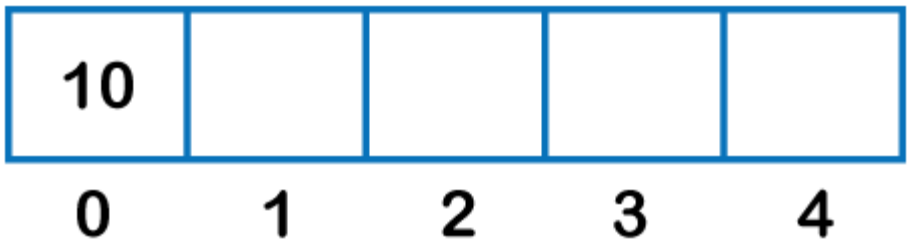
Step 4: EXIT

Let's understand the enqueue and dequeue operation through the diagrammatic representation.



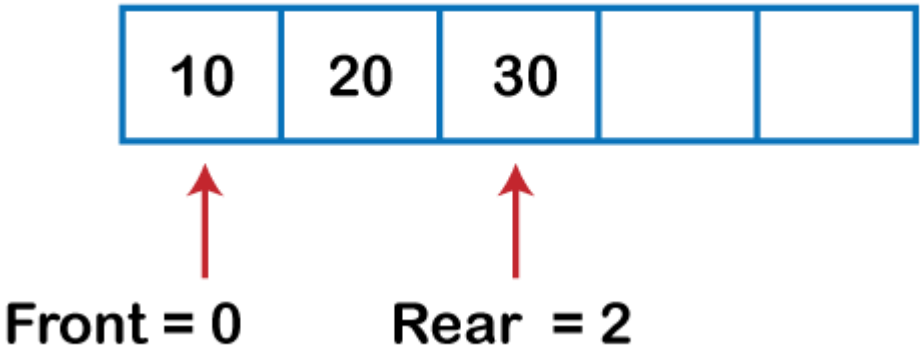
Front = -1

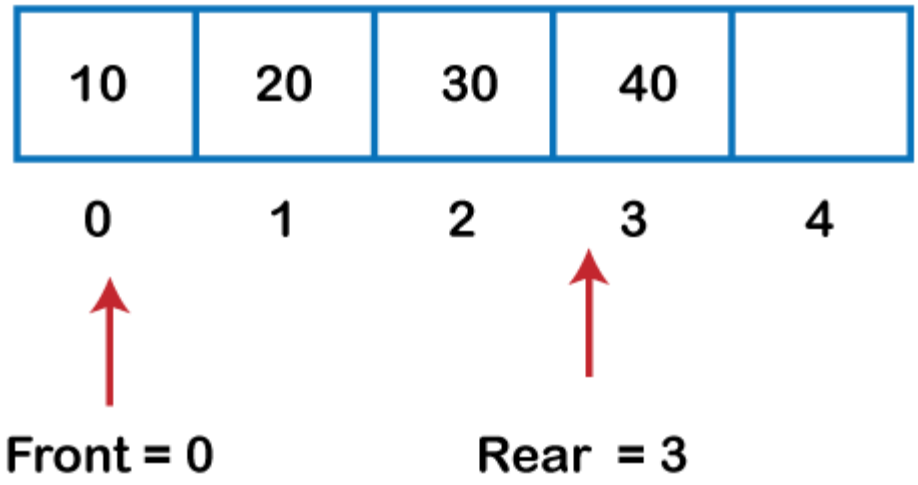
Rear = -1

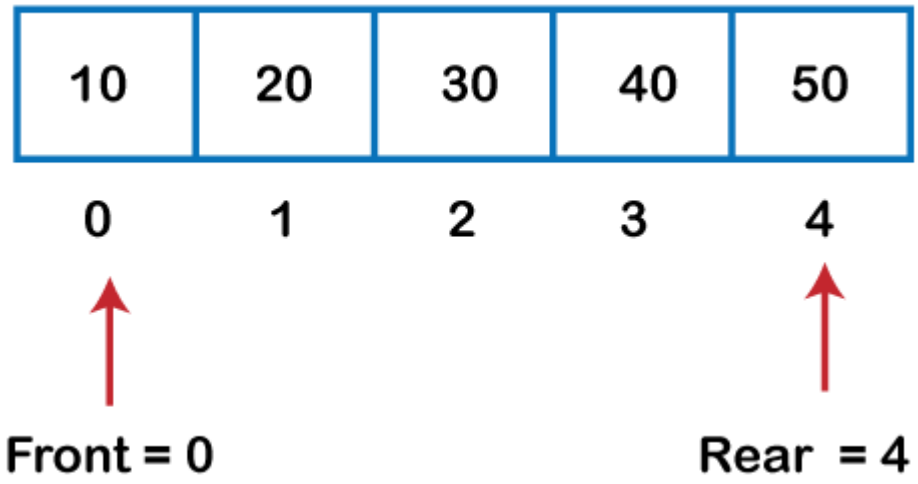


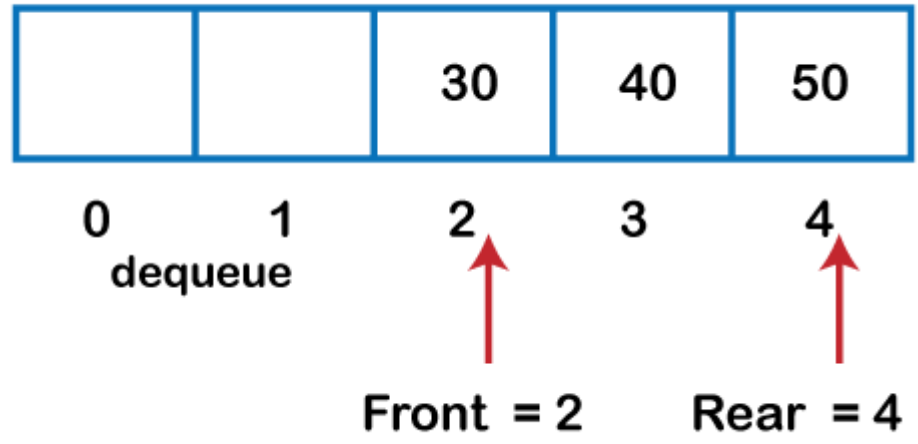
Front = 0

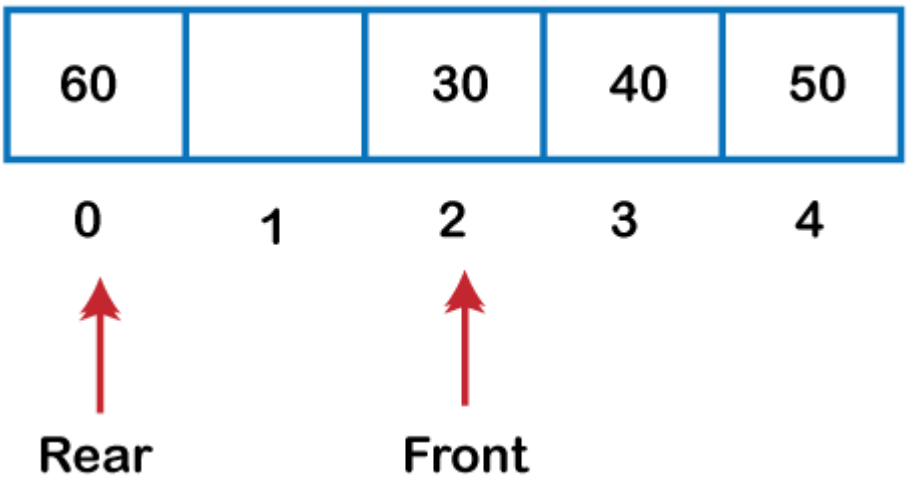
Rear = 0

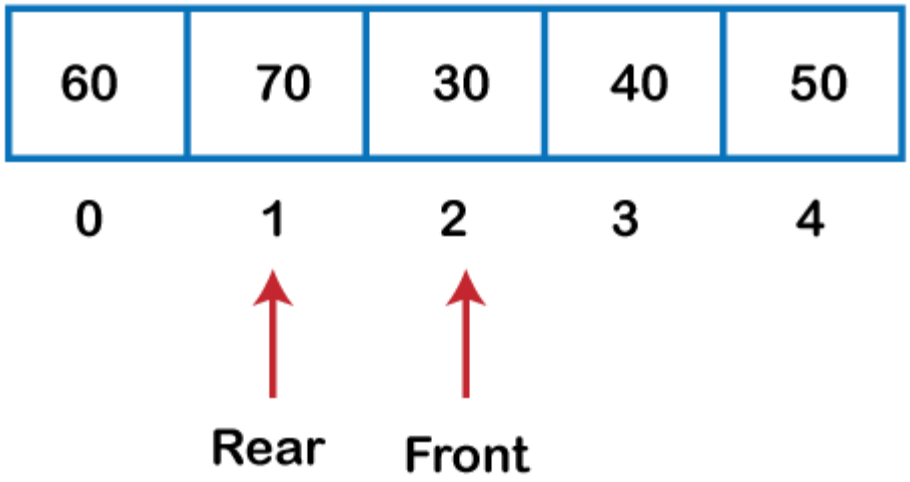

10
20
30
Front = 0
Rear = 2


10
20
30
40
0
1
2
3
4
Front = 0
Rear = 3


10
20
30
40
50
0
1
2
3
4
Front = 0
Rear = 4


30
40
50
0
1
2
3
4
dequeue
Front = 2
Rear = 4





Implementation of circular queue using Array

```
#include <stdio.h>


# define max 6

int queue[max];  // array declaration

int front=-1;

int rear=-1;
```

```
// function to insert an element in a circular queue
void enqueue(int element)
{
   if(front==-1 && rear==-1)   // condition to check queue is empty
   {
      front=0;
      rear=0;
      queue[rear]=element;
   }
   else if((rear+1)%max==front)  // condition to check queue is full
   {
      printf("Queue is overflow..");
   }
   else
   {
      rear=(rear+1)%max;      // rear is incremented
      queue[rear]=element;     // assigning a value to the queue at the rear position.
   }
}

// function to delete the element from the queue
int dequeue()
{
   if((front==-1) && (rear==-1))  // condition to check queue is empty
   {
      printf("\nQueue is underflow..");
   }
 else if(front==rear)
{
```

```
  printf("\nThe dequeued element is %d", queue[front]);
  front=-1;
  rear=-1;
}
else
{
   printf("\nThe dequeued element is %d", queue[front]);
  front=(front+1)%max;
}
}
// function to display the elements of a queue
void display()
{
   int i=front;
   if(front==-1 && rear==-1)
   {
      printf("\n Queue is empty..");
   }
   else
   {
      printf("\nElements in a Queue are :");
      while(i<=rear)
      {
         printf("%d,", queue[i]);
         i=(i+1)%max;
      }
   }
}
int main()
```

```
{
   int choice=1,x;   // variables declaration

   while(choice<4 && choice!=0)   // while loop
   {
   printf("\n Press 1: Insert an element");
   printf("\nPress 2: Delete an element");
   printf("\nPress 3: Display the element");
   printf("\nEnter your choice");
   scanf("%d", &choice);

   switch(choice)
   {

      case 1:

      printf("Enter the element which is to be inserted");
      scanf("%d", &x);
      enqueue(x);
      break;
      case 2:
      dequeue();
      break;
      case 3:
      display();

   }}
   return 0;
}
```

Implementation of circular queue using linked list

As we know that linked list is a linear data structure that stores two parts, i.e., data part and the address part where address part contains the address of the next node. Here, linked list is used to implement the circular queue; therefore, the linked list follows the properties of the Queue. When we are implementing the circular queue using linked list then both the enqueue and dequeue operations take O(1) time.

```
#include <stdio.h>
// Declaration of struct type node
struct node
{
   int data;
   struct node *next;
};
struct node *front=-1;
struct node *rear=-1;
// function to insert the element in the Queue
void enqueue(int x)
{
   struct node *newnode;  // declaration of pointer of struct node type.
   newnode=(struct node *)malloc(sizeof(struct node));  // allocating the memory to the newnode
   newnode->data=x;
   newnode->next=0;
   if(rear==-1)  // checking whether the Queue is empty or not.
```

```
    {
        front=rear=newnode;
        rear->next=front;
    }
    else
    {
        rear->next=newnode;
        rear=newnode;
        rear->next=front;
    }
}

// function to delete the element from the queue
void dequeue()
{
    struct node *temp;   // declaration of pointer of node type
    temp=front;
    if((front==-1)&&(rear==-1))  // checking whether the queue is empty or not
    {
        printf("\nQueue is empty");
    }
    else if(front==rear)  // checking whether the single element is left in the queue
    {
        front=rear=-1;
```

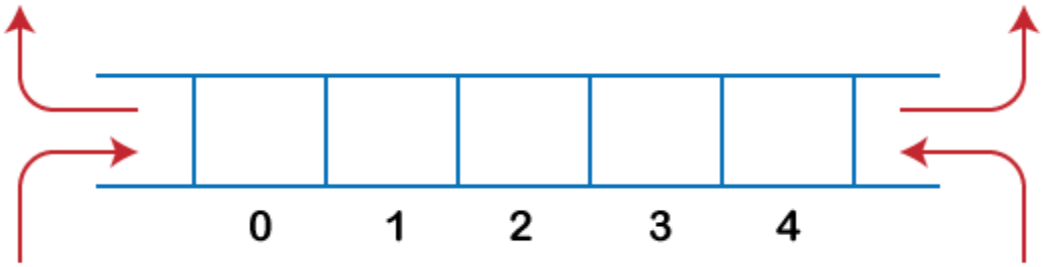
```
        free(temp);
    }
    else
    {
        front=front->next;
        rear->next=front;
        free(temp);
    }
}

// function to get the front of the queue
int peek()
{
    if((front==-1) &&(rear==-1))
    {
        printf("\nQueue is empty");
    }
    else
    {
        printf("\nThe front element is %d", front->data);
    }
}

// function to display all the elements of the queue
```

```
void display()
{
   struct node *temp;
   temp=front;
   printf("\n The elements in a Queue are : ");
   if((front==-1) && (rear==-1))
   {
      printf("Queue is empty");
   }

   else
   {
      while(temp->next!=front)
      {
         printf("%d,", temp->data);
         temp=temp->next;
      }
      printf("%d", temp->data);
   }
}

void main()
{
   enqueue(34);
```

```
    enqueue(10);
    enqueue(23);
    display();
    dequeue();
    peek();
}
```

Deque

The dequeue stands for **Double Ended Queue**. In the queue, the insertion takes place from one end while the deletion takes place from another end. The end at which the insertion occurs is known as the **rear end** whereas the end at which the deletion occurs is known as **front end**.

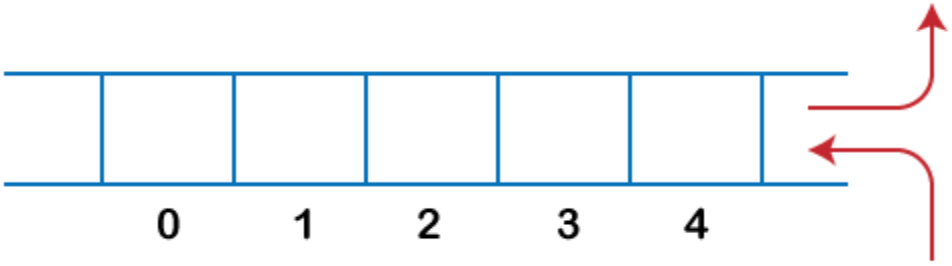


Deque is a linear data structure in which the insertion and deletion operations are performed from both ends. We can say that deque is a generalized version of the queue.

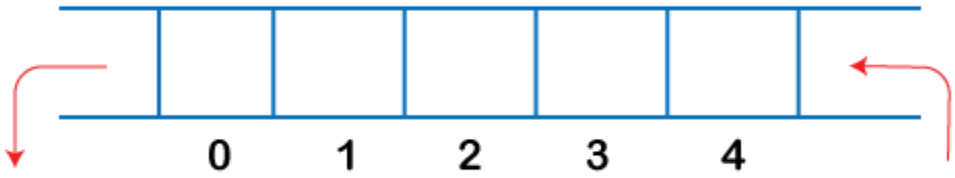
Let's look at some properties of deque.

- Deque can be used both as **stack** and **queue** as it allows the insertion and deletion operations on both ends.

In deque, the insertion and deletion operation can be performed from one side. The stack follows the LIFO rule in which both the insertion and deletion can be performed only from one end; therefore, we conclude that deque can be considered as a stack.

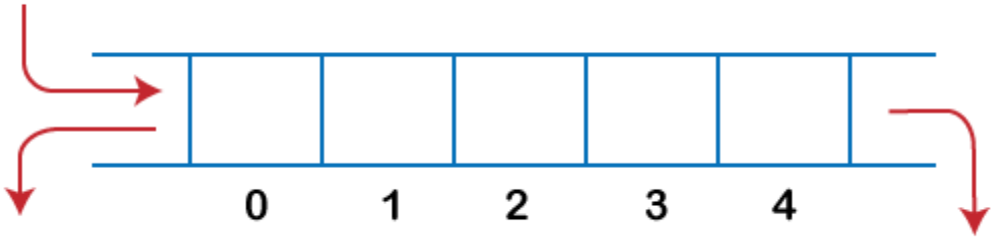


In deque, the insertion can be performed on one end, and the deletion can be done on another end. The queue follows the FIFO rule in which the element is inserted on one end and deleted from another end. Therefore, we conclude that the deque can also be considered as the queue.

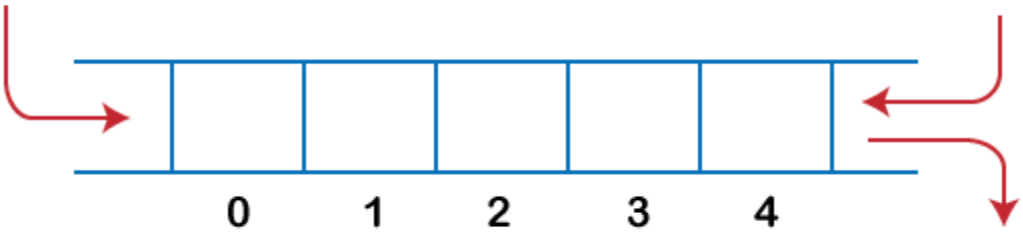


There are two types of Queues, **Input-restricted queue**, and **output-restricted queue**.

1. **Input-restricted queue:** The input-restricted queue means that some restrictions are applied to the insertion. In input-restricted queue, the insertion is applied to one end while the deletion is applied from both the ends.



Output-restricted queue: The output-restricted queue means that some restrictions are applied to the deletion operation. In an output-restricted queue, the deletion can be applied only from one end, whereas the insertion is possible from both ends.



Operations on Deque

The following are the operations applied on deque:

- Insert at front
- Delete from end
- insert at rear
- delete from rear

Other than insertion and deletion, we can also perform **peek** operation in deque. Through **peek** operation, we can get the **front** and the **rear** element of the dequeue.

We can perform two more operations on dequeue:

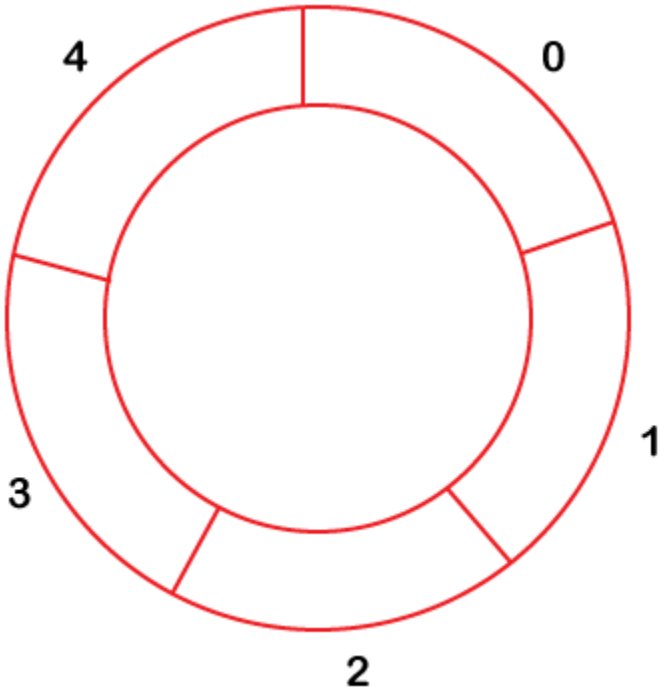
- **isFull():** This function returns a true value if the stack is full; otherwise, it returns a false value.
- **isEmpty():** This function returns a true value if the stack is empty; otherwise it returns a false value.

Memory Representation

The deque can be implemented using two data structures, i.e., **circular array**, and **doubly linked list**. To implement the deque using circular array, we first should know **what is circular array**.

What is a circular array?

An array is said to be **circular** if the last element of the array is connected to the first element of the array. Suppose the size of the array is 4, and the array is full but the first location of the array is empty. If we want to insert the array element, it will not show any overflow condition as the last element is connected to the first element. The value which we want to insert will be added in the first location of the array.



Applications of Deque

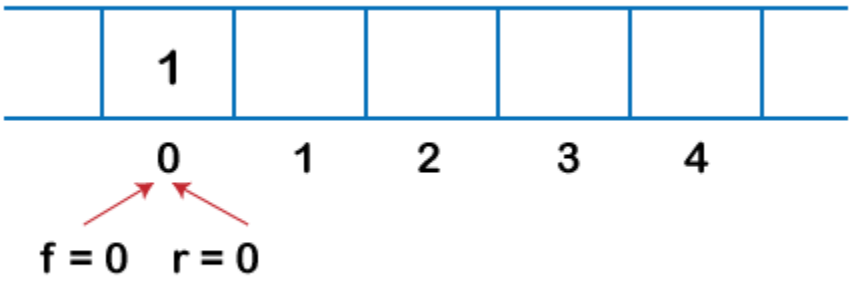
- The deque can be used as a **stack** and **queue**; therefore, it can perform both redo and undo operations.
- It can be used as a palindrome checker means that if we read the string from both ends, then the string would be the same.
- It can be used for multiprocessor scheduling. Suppose we have two processors, and each processor has one process to execute. Each processor is assigned with a process or a job, and each process contains multiple threads. Each processor maintains a deque that contains threads that are ready to execute. The processor executes a process, and if a process creates a child process then that process will be inserted at the front of the deque of the parent process. Suppose the processor P_2 has completed the execution of all its threads then it steals the thread from the rear end of the processor P_1 and adds to the front end of the processor P_2. The processor P_2 will take the thread from the front end; therefore, the deletion takes from both the ends, i.e., front and rear end. This is known as the **A-steal algorithm** for scheduling.

Implementation of Deque using a circular array

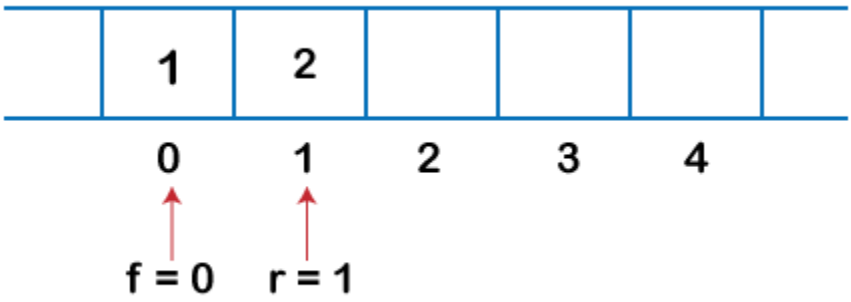
The following are the steps to perform the operations on the Deque:

Enqueue operation

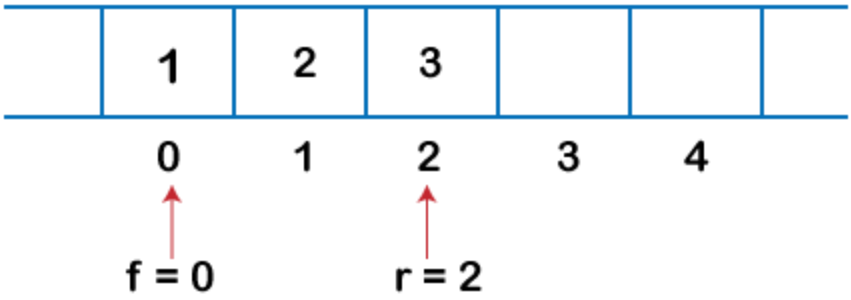
1. Initially, we are considering that the deque is empty, so both front and rear are set to -1, i.e., **f = -1** and **r = -1**.
2. As the deque is empty, so inserting an element either from the front or rear end would be the same thing. Suppose we have inserted element 1, then **front is equal to 0,** and the **rear is also equal to 0.**



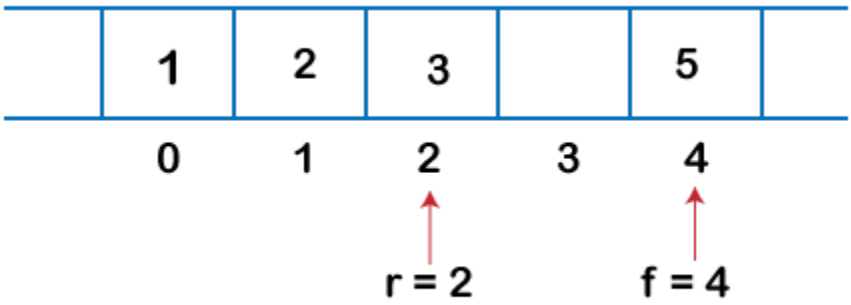
3. Suppose we want to insert the next element from the rear. To insert the element from the rear end, we first need to increment the rear, i.e., **rear=rear+1**. Now, the rear is pointing to the second element, and the front is pointing to the first element.



1. Suppose we are again inserting the element from the rear end. To insert the element, we will first increment the rear, and now rear points to the third element.



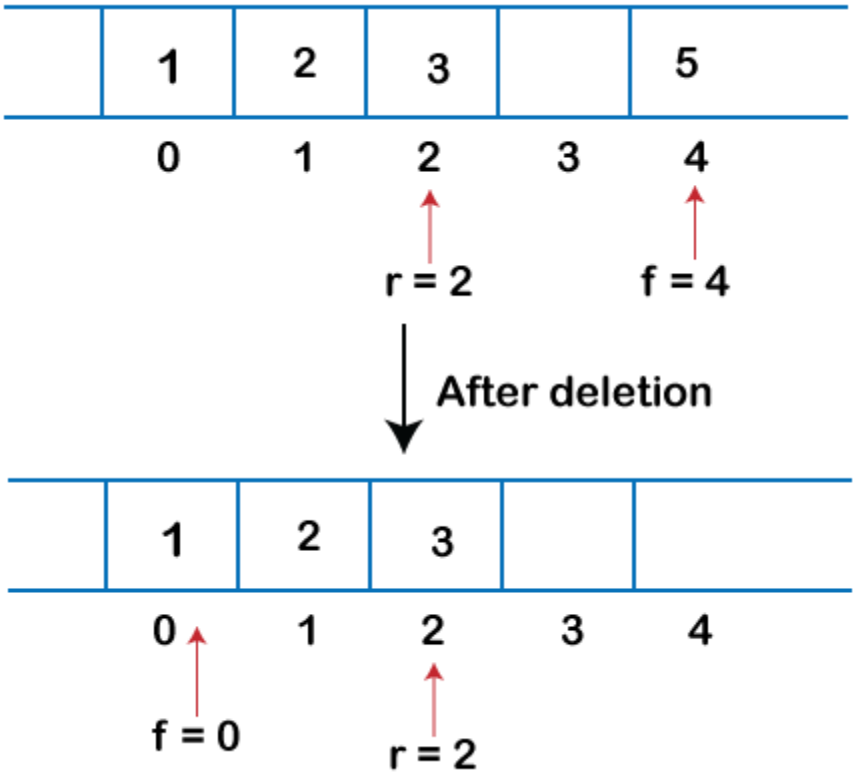
2. If we want to insert the element from the front end, and insert an element from the front, we have to decrement the value of front by 1. If we decrement the front by 1, then the front points to -1 location, which is not any valid location in an array. So, we set the front as **(n -1),** which is equal to 4 as n is 5. Once the front is set, we will insert the value as shown in the below figure:



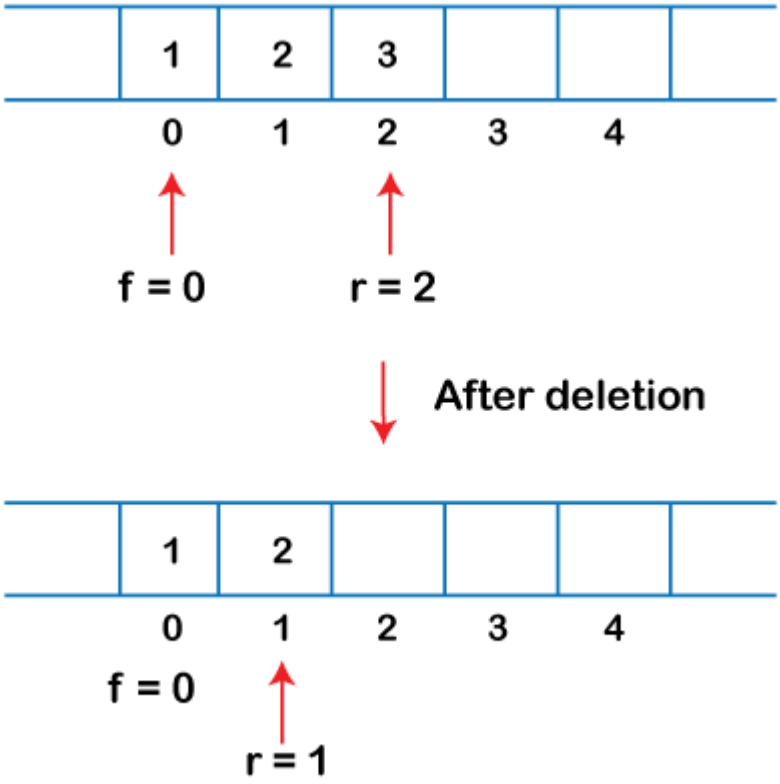
Dequeue Operation

1. If the front is pointing to the last element of the array, and we want to perform the delete operation from the front. To delete any element from the front, we need to set **front=front+1**. Currently, the value of the front is equal to 4, and if we increment the value of front, it becomes 5 which is not a valid index. Therefore, we conclude that if front

points to the last element, then front is set to 0 in case of delete operation.

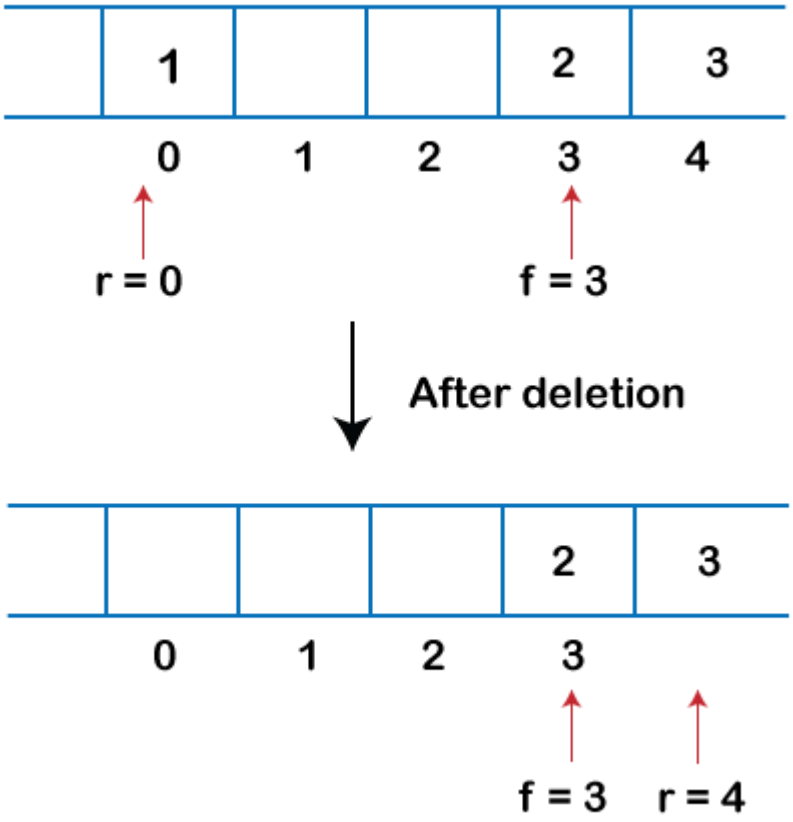


2. If we want to delete the element from rear end then we need to decrement the rear value by 1, i.e., **rear=rear-1** as shown in the below figure:



3. If the rear is pointing to the first element, and we want to delete the element from the rear end then we have to set **rear=n-1** where **n** is the size of the array as shown in the below

figure:



Let's create a program of deque.

The following are the six functions that we have used in the below program:

- **enqueue_front():** It is used to insert the element from the front end.
- **enqueue_rear():** It is used to insert the element from the rear end.
- **dequeue_front():** It is used to delete the element from the front end.
- **dequeue_rear():** It is used to delete the element from the rear end.
- **getfront():** It is used to return the front element of the deque.
- **getrear():** It is used to return the rear element of the deque.

⇨ **Demo**

```
#define size 5

#include <stdio.h>
```

```
int deque[size];
int f=-1, r=-1;
//  enqueue_front function will insert the value from the front
void enqueue_front(int x)
{
   if((f==0 && r==size-1) || (f==r+1))
   {
      printf("deque is full");
   }
   else if((f==-1) && (r==-1))
   {
      f=r=0;
      deque[f]=x;
   }
   else if(f==0)
   {
      f=size-1;
      deque[f]=x;
   }
   else
   {
      f=f-1;
      deque[f]=x;
   }
}

// enqueue_rear function will insert the value from the rear
void enqueue_rear(int x)
{
```

```
    if((f==0 && r==size-1) || (f==r+1))
    {
        printf("deque is full");
    }
    else if((f==-1) && (r==-1))
    {
        r=0;
        deque[r]=x;
    }
    else if(r==size-1)
    {
        r=0;
        deque[r]=x;
    }
    else
    {
        r++;
        deque[r]=x;
    }

}

// display function prints all the value of deque.
void display()
{
    int i=f;
    printf("\n Elements in a deque : ");

    while(i!=r)
```

```
    {
        printf("%d ",deque[i]);
        i=(i+1)%size;
    }
     printf("%d",deque[r]);
}

// getfront function retrieves the first value of the deque.
void getfront()
{
    if((f==-1) && (r==-1))
    {
        printf("Deque is empty");
    }
    else
    {
        printf("\nThe value of the front is: %d", deque[f]);
    }

}

// getrear function retrieves the last value of the deque.
void getrear()
{
    if((f==-1) && (r==-1))
    {
        printf("Deque is empty");
    }
    else
```

```
    {
        printf("\nThe value of the rear is: %d", deque[r]);
    }

}

// dequeue_front() function deletes the element from the front
void dequeue_front()
{
    if((f==-1) && (r==-1))
    {
        printf("Deque is empty");
    }
    else if(f==r)
    {
        printf("\nThe deleted element is %d", deque[f]);
        f=-1;
        r=-1;

    }
     else if(f==(size-1))
     {
         printf("\nThe deleted element is %d", deque[f]);
         f=0;
     }
     else
     {
          printf("\nThe deleted element is %d", deque[f]);
          f=f+1;
```

```
    }
}

// dequeue_rear() function deletes the element from the rear
void dequeue_rear()
{
   if((f==-1) && (r==-1))
   {
      printf("Deque is empty");
   }
   else if(f==r)
   {
      printf("\nThe deleted element is %d", deque[r]);
      f=-1;
      r=-1;

   }
    else if(r==0)
    {
       printf("\nThe deleted element is %d", deque[r]);
       r=size-1;
    }
    else
    {
        printf("\nThe deleted element is %d", deque[r]);
        r=r-1;
    }
}
```

```
int main()
{
   // inserting a value from the front.
    enqueue_front(2);
  // inserting a value from the front.
    enqueue_front(1);
  // inserting a value from the rear.
    enqueue_rear(3);
  // inserting a value from the rear.
    enqueue_rear(5);
  // inserting a value from the rear.
    enqueue_rear(8);
  // Calling the display function to retrieve the values of deque
    display();
 // Retrieve the front value
    getfront();
// Retrieve the rear value.
    getrear();
// deleting a value from the front
dequeue_front();
//deleting a value from the rear
dequeue_rear();
 // Calling the display function to retrieve the values of deque
 display();
    return 0;
}
```

All in one

```
#include <stdio.h>

#define size 5


int deque[size];


int f=-1, r=-1;


//  enqueue_front function will insert the value from the front

void enqueue_front(int x)

{

   if((f==0 && r==size-1) || (f==r+1))

   {

      printf("deque is full");

   }

   else if((f==-1) && (r==-1))

   {

      f=r=0;

      deque[f]=x;

   }

   else if(f==0)

   {

      f=size-1;

      deque[f]=x;

   }

   else

   {

      f=f-1;

      deque[f]=x;
```

```
    }
}

// enqueue_rear function will insert the value from the rear
void enqueue_rear(int x)
{
    if((f==0 && r==size-1) || (f==r+1))
    {
        printf("deque is full");
    }
    else if((f==-1) && (r==-1))
    {
            f=0;
        r=0;
        deque[r]=x;
    }
    else if(r==size-1)
    {
        r=0;
        deque[r]=x;
    }
    else
    {
        r++;
        deque[r]=x;
    }

}
```

```
// display function prints all the value of deque.
void display()
{
   int i=f;
   printf("\n Elements in a deque : ");

   while(i!=r)
   {
      printf("%d ",deque[i]);
      i=(i+1)%size;
   }
    printf("%d",deque[r]);
}

// getfront function retrieves the first value of the deque.
void getfront()
{
   if((f==-1) && (r==-1))
   {
      printf("Deque is empty");
   }
   else
   {
      printf("\nThe value of the front is: %d", deque[f]);
```

```
    }

}

// getrear function retrieves the last value of the deque.
void getrear()
{
    if((f==-1) && (r==-1))
    {
        printf("Deque is empty");
    }
    else
    {
        printf("\nThe value of the rear is: %d", deque[r]);
    }

}

// dequeue_front() function deletes the element from the front
void dequeue_front()
{
    if((f==-1) && (r==-1))
    {
        printf("Deque is empty");
    }
    else if(f==r)
    {
        printf("\nThe deleted element is %d", deque[f]);
        f=-1;
```

```
        r=-1;

    }
     else if(f==(size-1))
     {
        printf("\nThe deleted element is %d", deque[f]);
        f=0;
     }
     else
     {
         printf("\nThe deleted element is %d", deque[f]);
         f=f+1;
     }
}

// dequeue_rear() function deletes the element from the rear
void dequeue_rear()
{
   if((f==-1) && (r==-1))
   {
      printf("Deque is empty");
   }
   else if(f==r)
   {
      printf("\nThe deleted element is %d", deque[r]);
      f=-1;
      r=-1;

   }
```

```
    else if(r==0)
    {
       printf("\nThe deleted element is %d", deque[r]);
       r=size-1;
    }
    else
    {
        printf("\nThe deleted element is %d", deque[r]);
        r=r-1;
    }
}



void peek()
{
   int x, temp=0;
            printf("\nSelect position to peek:- ");
            scanf("%d",&x);

   if(f==-1 && r==-1)
   {
      printf("\n Queue is empty..");
   }
   else
   {
                        int i=f, flag=0;

      while(i!=r)
```

```
    {
        if(temp==x)
        {
                printf("\nElement at %d position is : %d\n",temp, deque[i]);
                flag=1;
                        }
                        temp=(temp+1)%size;
       i=(i+1)%size;

    }

                if(temp==x)
        {
                printf("\nThe last value is :- %d\n", deque[i]);
                flag=1;
                }

                else if(flag!=1)
                {
                        printf("Element is not found.");
                }
  }
}




void locate()
{
   int y, temp=0;
```

```
        printf("\nselect number for find:- ");
        scanf("%d",&y);

if(f==-1 && r==-1)
{
   printf("\n Queue is empty..\n");
}
else
{
                int i=f, flag=0;

   while(i!=r)
   {
        if(deque[i]==y)
        {
                printf("\nElement is at index: %d with pos from front is %d\n",temp,i);
                flag=1;
                        }
      i=(i+1)%size;
      temp=(temp+1)%size;

   }
                if(deque[i]==y)
        {
                printf("\nThe last value is at:- %d with new last pos is %d\n", temp,i);
                flag=1;
                }

                else if(flag!=1)
```

```
                {
                        printf("Element is not found.");
                }
    }
}



int main()
{
    int choice=1,x;   // variables declaration

    do // do while loop
    {
            printf("\n\nPress 1:Insert an element at front");
            printf("\nPress 2:Insert an element at rear");
            printf("\nPress 3: Delete an element from front");
            printf("\nPress 4: Delete an element from rear");
            printf("\nPress 5: Display the element");
            printf("\nPress 6: peek the element");
            printf("\nPress 7: locate the element\n");
            printf("\nEnter your choice\n");
            scanf("%d", &choice);


            switch(choice)
            {
               case 1:
                        printf("\nEnter the front element to be inserted\n");
```

```
                scanf("%d", &x);
                        enqueue_front(x);
            break;
                case 2:
                printf("\nEnter the rear element to be inserted\n");
                scanf("%d", &x);
                        enqueue_rear(x);
            break;
            case 3:
                dequeue_front();
            break;
            case 4:
                dequeue_rear();
            break;
            case 5:
              display();
                        break;
                        case 6:
              peek();
                        break;
                        case 7:
              locate();
                        break;

          }
        }  while(choice<8 && choice>0) ;
   return 0;
}
```

```
//
//int main()
//{
//   // inserting a value from the front.
//    enqueue_front(2);
//  // inserting a value from the front.
//    enqueue_front(1);
//  // inserting a value from the rear.
//    enqueue_rear(3);
//  // inserting a value from the rear.
//    enqueue_rear(5);
//  // inserting a value from the rear.
//    enqueue_rear(8);
//  // Calling the display function to retrieve the values of deque
//    display();
// // Retrieve the front value
//    getfront();
//// Retrieve the rear value.
//    getrear();
//// deleting a value from the front
//dequeue_front();
////deleting a value from the rear
//dequeue_rear();
```

```
// // Calling the display function to retrieve the values of deque
// display();
//    return 0;
//}
```

What is a priority queue?

A priority queue is an abstract data type that behaves similarly to the normal queue except that each element has some priority, i.e., the element with the highest priority would come first in a priority queue. The priority of the elements in a priority queue will determine the order in which elements are removed from the priority queue.

The priority queue supports only comparable elements, which means that the elements are either arranged in an ascending or descending order.

For example, suppose we have some values like 1, 3, 4, 8, 14, 22 inserted in a priority queue with an ordering imposed on the values is from least to the greatest. Therefore, the 1 number would be having the highest priority while 22 will be having the lowest priority.

Characteristics of a Priority queue

A priority queue is an extension of a queue that contains the following characteristics:

- Every element in a priority queue has some priority associated with it.
- An element with the higher priority will be deleted before the deletion of the lesser priority.
- If two elements in a priority queue have the same priority, they will be arranged using the FIFO principle.

Let's understand the priority queue through an example.

We have a priority queue that contains the following values:

1, 3, 4, 8, 14, 22

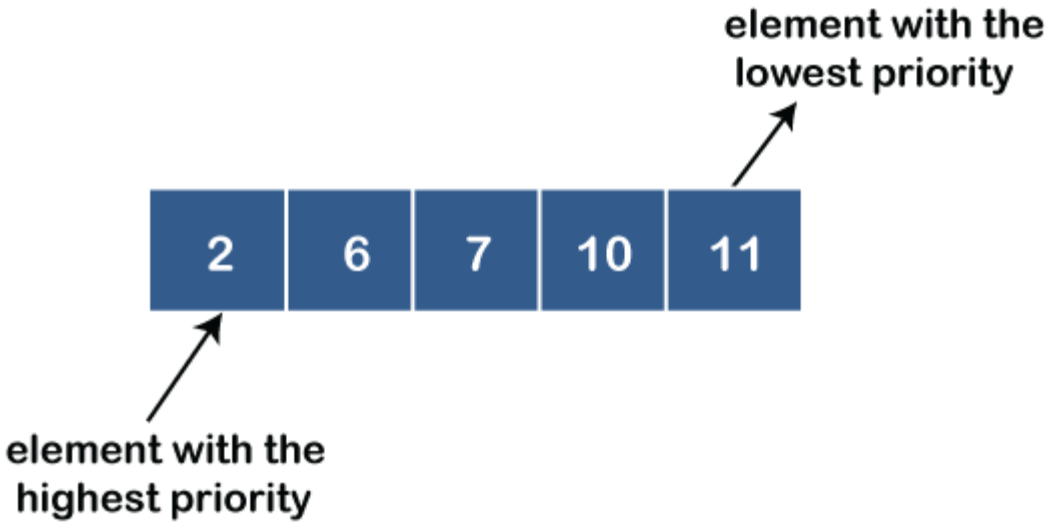
All the values are arranged in ascending order. Now, we will observe how the priority queue will look after performing the following operations:

- **poll():** This function will remove the highest priority element from the priority queue. In the above priority queue, the '1' element has the highest priority, so it will be removed from the priority queue.
- **add(2):** This function will insert '2' element in a priority queue. As 2 is the smallest element among all the numbers so it will obtain the highest priority.
- **poll():** It will remove '2' element from the priority queue as it has the highest priority queue.
- **add(5):** It will insert 5 element after 4 as 5 is larger than 4 and lesser than 8, so it will obtain the third highest priority in a priority queue.

Types of Priority Queue

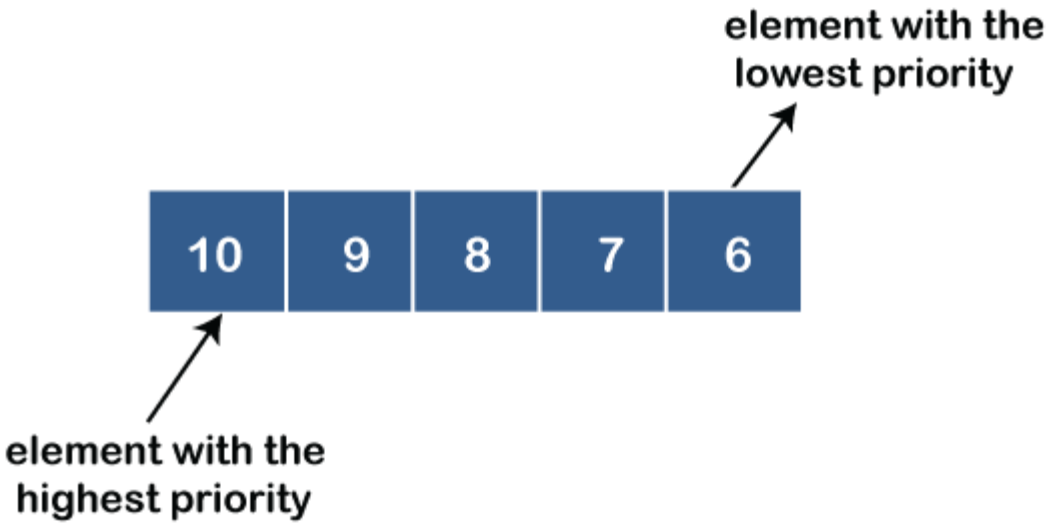
There are two types of priority queue:

- **Ascending order priority queue:** In ascending order priority queue, a lower priority number is given as a higher priority in a priority. For example, we take the numbers from 1 to 5 arranged in an ascending order like 1,2,3,4,5; therefore, the smallest number, i.e., 1 is given as the highest priority in a priority queue.



- **Descending order priority queue:** In descending order priority queue, a higher priority number is given as a higher priority in a priority. For example, we take the numbers from 1 to 5 arranged in descending order like 5, 4, 3, 2, 1; therefore, the largest number, i.e., 5

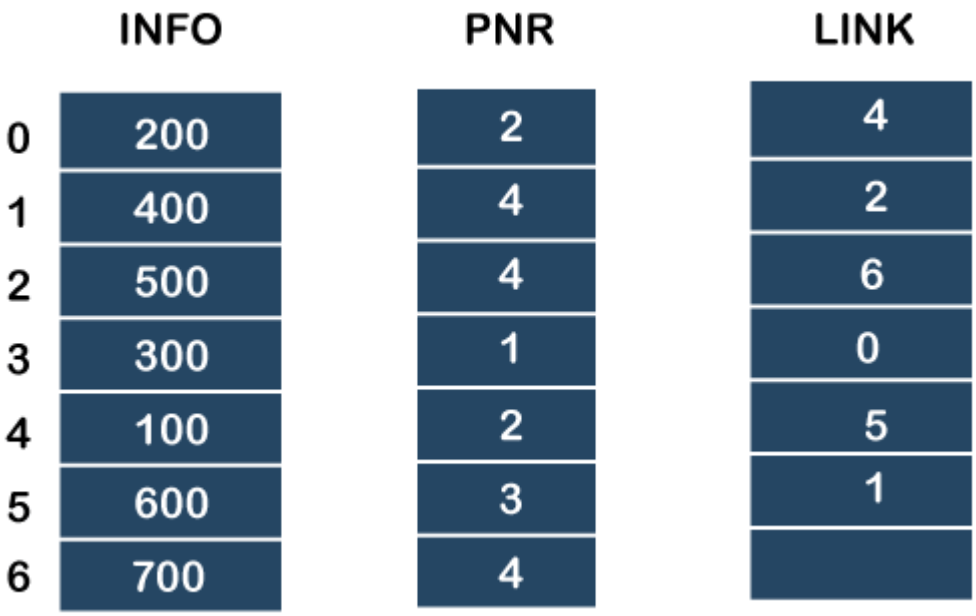
is given as the highest priority in a priority queue.



Representation of priority queue

Now, we will see how to represent the priority queue through a one-way list.

We will create the priority queue by using the list given below in which **INFO** list contains the data elements, **PRN** list contains the priority numbers of each data element available in the **INFO** list, and LINK basically contains the address of the next node.



Let's create the priority queue step by step.

In the case of priority queue, lower priority number is considered the higher priority, i.e., lower priority number = higher priority.

Step 1: In the list, lower priority number is 1, whose data value is 333, so it will be inserted in the list as shown in the below diagram:

Step 2: After inserting 333, priority number 2 is having a higher priority, and data values associated with this priority are 222 and 111. So, this data will be inserted based on the FIFO principle; therefore 222 will be added first and then 111.

Step 3: After inserting the elements of priority 2, the next higher priority number is 4 and data elements associated with 4 priority numbers are 444, 555, 777. In this case, elements would be inserted based on the FIFO principle; therefore, 444 will be added first, then 555, and then 777.

Step 4: After inserting the elements of priority 4, the next higher priority number is 5, and the value associated with priority 5 is 666, so it will be inserted at the end of the queue.

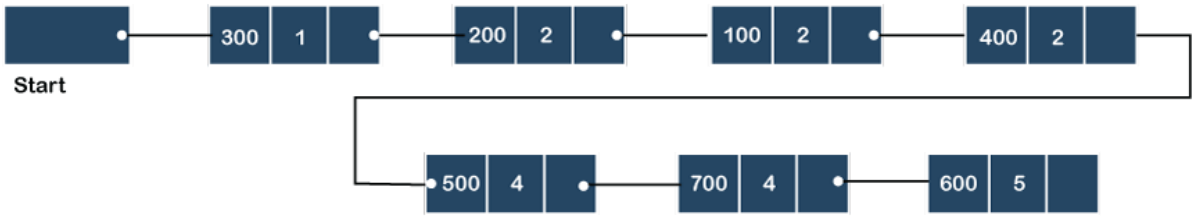
In the case of priority queue, lower priority number is considered the higher priority, i.e., lower priority number = higher priority.

Step 1: In the list, lower priority number is 1, whose data value is 333, so it will be inserted in the list as shown in the below diagram:

Step 2: After inserting 333, priority number 2 is having a higher priority, and data values associated with this priority are 222 and 111. So, this data will be inserted based on the FIFO principle; therefore 222 will be added first and then 111.

Step 3: After inserting the elements of priority 2, the next higher priority number is 4 and data elements associated with 4 priority numbers are 444, 555, 777. In this case, elements would be inserted based on the FIFO principle; therefore, 444 will be added first, then 555, and then 777.

Step 4: After inserting the elements of priority 4, the next higher priority number is 5, and the value associated with priority 5 is 666, so it will be inserted at the end of the queue.



Implementation of Priority Queue

The priority queue can be implemented in four ways that include arrays, linked list, heap data structure and binary search tree. The heap data structure is the most efficient way of implementing the priority queue, so we will implement the priority queue using a heap data structure in this topic. Now, first we understand the reason why heap is the most efficient way among all the other data structures.

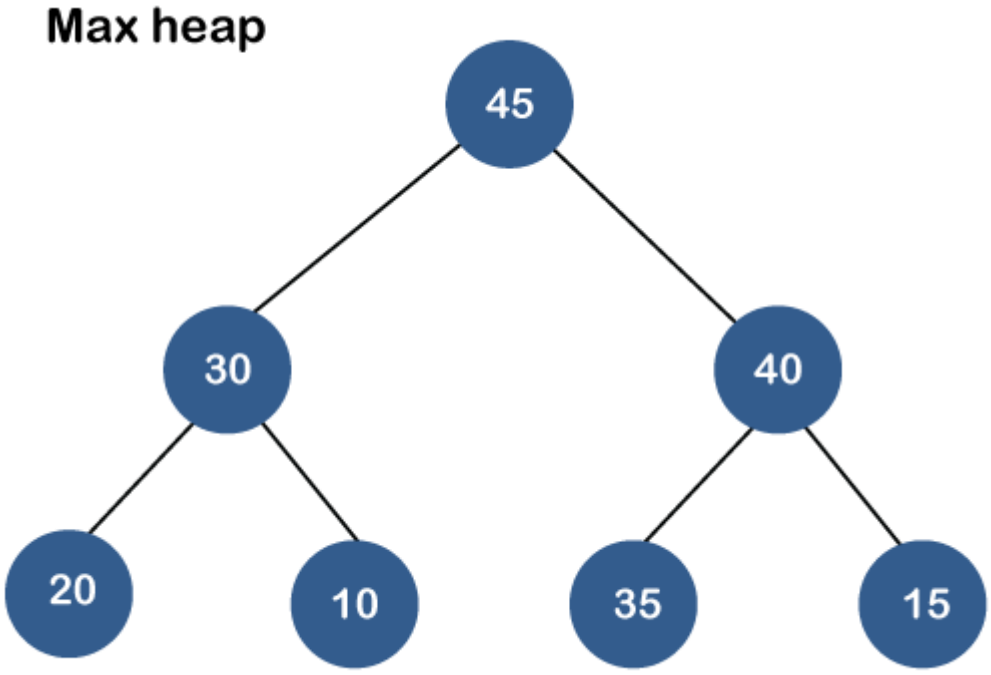
Analysis of complexities using different implementations

Implementation	Add	Remove
Linked list	O(1)	O(n)
Binary heap	O(logn)	O(logn)
Binary search tree	O(logn)	O(logn)

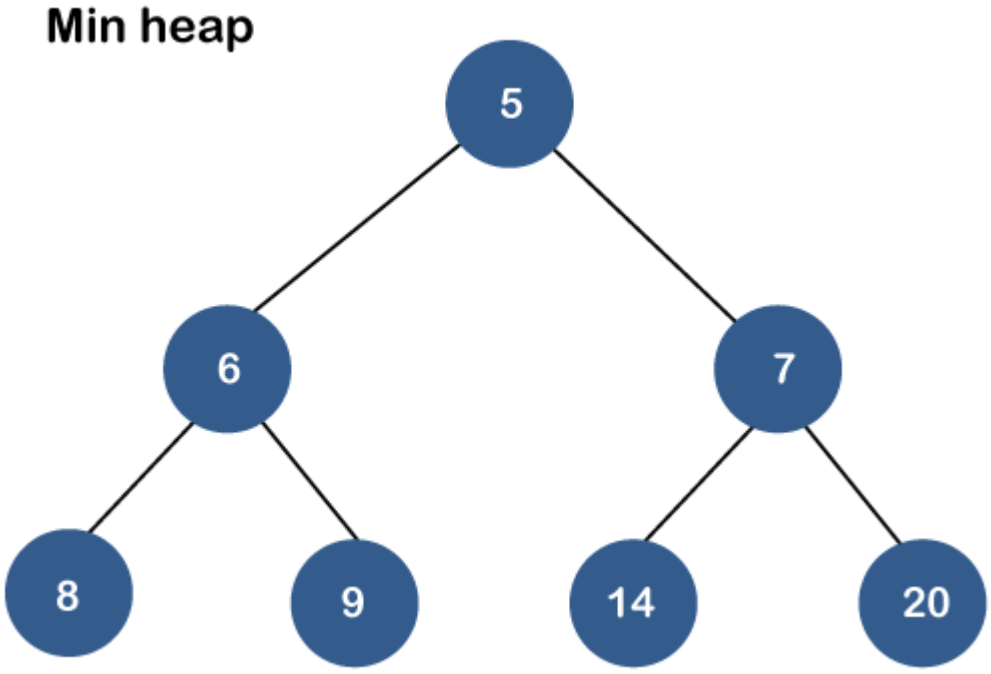
What is Heap?

A heap is a tree-based data structure that forms a complete binary tree, and satisfies the heap property. If A is a parent node of B, then A is ordered with respect to the node B for all nodes A and B in a heap. It means that the value of the parent node could be more than or equal to the value of the child node, or the value of the parent node could be less than or equal to the value of the child node. Therefore, we can say that there are two types of heaps:

- **Max heap:** The max heap is a heap in which the value of the parent node is greater than the value of the child nodes.



- **Min heap:** The min heap is a heap in which the value of the parent node is less than the value of the child nodes.



Both the heaps are the binary heap, as each has exactly two child nodes.

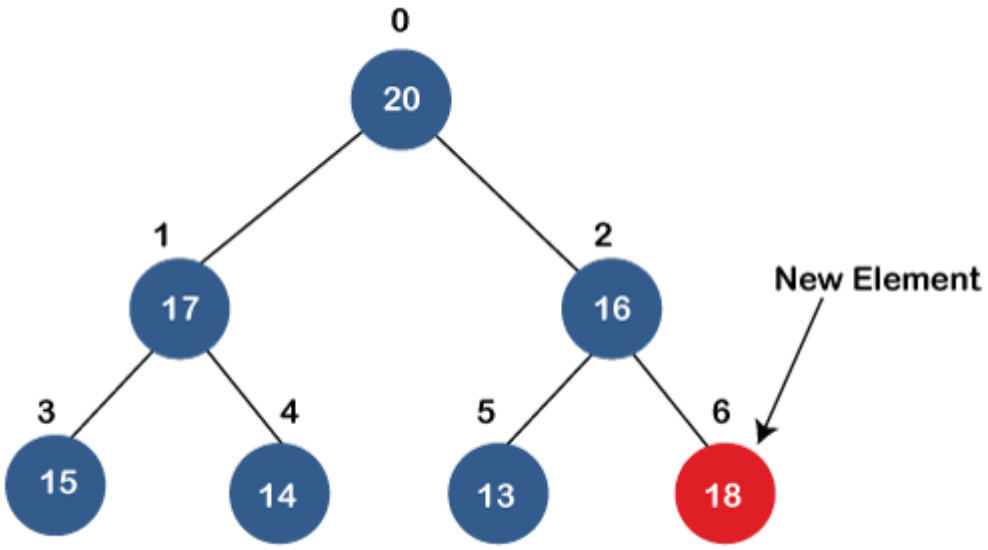
Priority Queue Operations

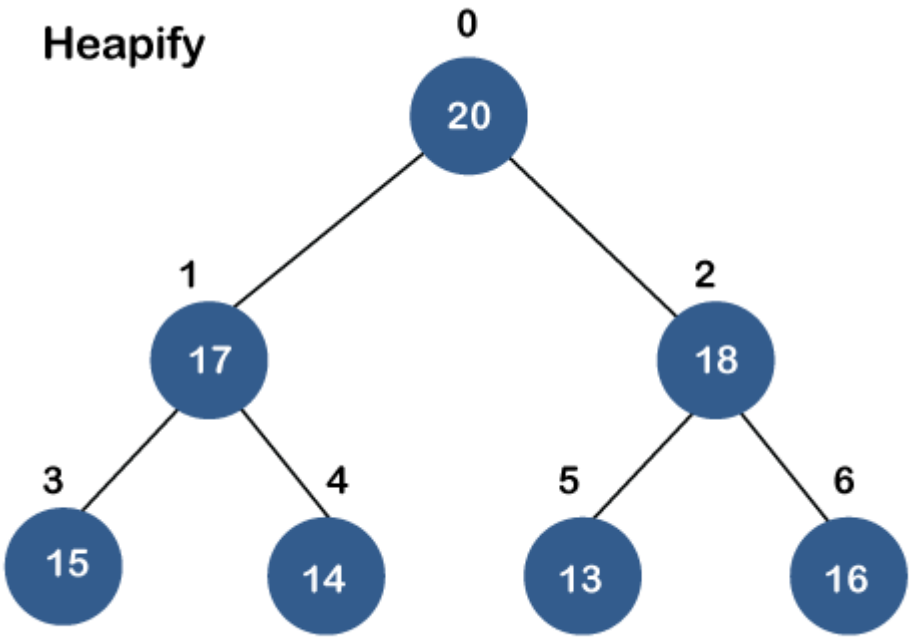
The common operations that we can perform on a priority queue are insertion, deletion and peek. Let's see how we can maintain the heap data structure.

- **Inserting the element in a priority queue (max heap)**

If we insert an element in a priority queue, it will move to the empty slot by looking from top to bottom and left to right.

If the element is not in a correct place then it is compared with the parent node; if it is found out of order, elements are swapped. This process continues until the element is placed in a correct position.





- **Removing the minimum element from the priority queue**

As we know that in a max heap, the maximum element is the root node. When we remove the root node, it creates an empty slot. The last inserted element will be added in this empty slot. Then, this element is compared with the child nodes, i.e., left-child and right child, and swap with the smaller of the two. It keeps moving down the tree until the heap property is restored.

Applications of Priority queue

The following are the applications of the priority queue:

- It is used in the Dijkstra's shortest path algorithm.
- It is used in prim's algorithm
- It is used in data compression techniques like Huffman code.
- It is used in heap sort.
- It is also used in operating system like priority scheduling, load balancing and interrupt handling.

Program to create the priority queue using the binary max heap.

In the above program, we have created the following functions:

- **int parent(int i):** This function returns the index of the parent node of a child node, i.e., i.
- **int left_child(int i):** This function returns the index of the left child of a given index, i.e., i.
- **int right_child(int i):** This function returns the index of the right child of a given index, i.e., i.
- **void moveUp(int i):** This function will keep moving the node up the tree until the heap property is restored.
- **void moveDown(int i):** This function will keep moving the node down the tree until the heap property is restored.
- **void removeMax():** This function removes the element which is having the highest priority.
- **void insert(int p):** It inserts the element in a priority queue which is passed as an argument in a function**.**
- **void delete(int i):** It deletes the element from a priority queue at a given index.
- **int get_Max():** It returns the element which is having the highest priority, and we know that in max heap, the root node contains the element which has the largest value, and highest priority.
- **int get_Min():** It returns the element which is having the minimum priority, and we know that in max heap, the last node contains the element which has the smallest value, and lowest priority.

```
#include <stdio.h>
#include <stdio.h>
int heap[40];
int size=-1;
```

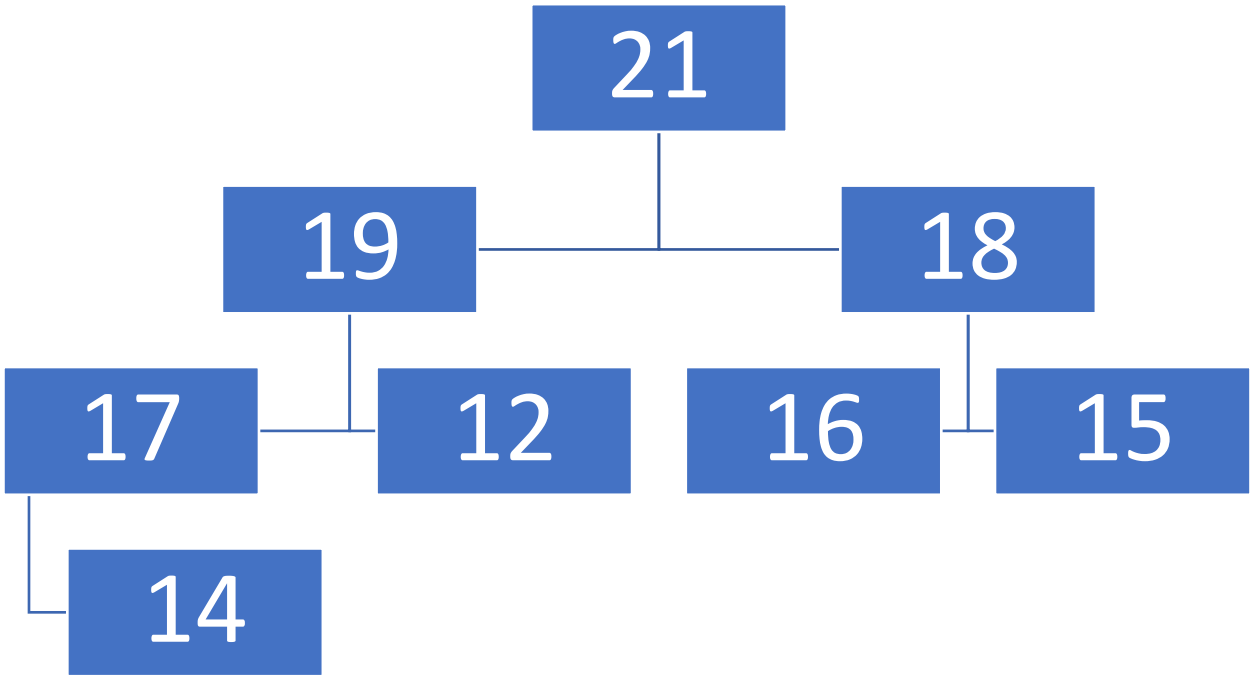
```
// retrieving the parent node of the child node
int parent(int i)
{

   return (i - 1) / 2;
}

// retrieving the left child of the parent node.
int left_child(int i)
{
 return i+1;
}
// retrieving the right child of the parent
int right_child(int i)
{
 return i+2;
}
// Returning the element having the highest priority
int get_Max()
{
   return heap[0];
}
//Returning the element having the minimum priority
int get_Min()
{
   return heap[size];
}
// function to move the node up the tree in order to restore the heap property.
void moveUp(int i)
```

```
{
   while (i > 0)
   {
      // swapping parent node with a child node
      if(heap[parent(i)] < heap[i]) {

      int temp;
      temp=heap[parent(i)];
      heap[parent(i)]=heap[i];
      heap[i]=temp;



   }
     // updating the value of i to i/2
     i=i/2;
   }
}

//function to move the node down the tree in order to restore the heap property.
void moveDown(int k)
{
   int index = k;

   // getting the location of the Left Child
   int left = left_child(k);

   if (left <= size && heap[left] > heap[index]) {
      index = left;
   }
```

```
   // getting the location of the Right Child
   int right = right_child(k);

   if (right <= size && heap[right] > heap[index]) {
      index = right;
   }

   // If k is not equal to index
   if (k != index) {
     int temp;
     temp=heap[index];
     heap[index]=heap[k];
     heap[k]=temp;
       moveDown(index);
   }
}

// Removing the element of maximum priority
void removeMax()
{
   int r= heap[0];
   heap[0]=heap[size];
   size=size-1;
   moveDown(0);
}
//inserting the element in a priority queue
void insert(int p)
{
```

```
    size = size + 1;
    heap[size] = p;

    // move Up to maintain heap property
    moveUp(size);
}

//Removing the element from the priority queue at a given index i.
void delete(int i)
{
    heap[i] = heap[0] + 1;

   // move the node stored at ith location is shifted to the root node
    moveUp(i);

    // Removing the node having maximum priority
    removeMax();
}
int main()
{
    // Inserting the elements in a priority queue

    insert(20);
    insert(19);
    insert(21);
    insert(18);
    insert(12);
    insert(17);
    insert(15);
```

```
   insert(16);
   insert(14);
   int i=0;

 printf("Elements in a priority queue are : ");
 for(int i=0;i<=size;i++)
   {
     printf("%d ",heap[i]);
   }
   delete(2); // deleting the element whose index is 2.
   printf("\nElements in a priority queue after deleting the element are : ");
   for(int i=0;i<=size;i++)
   {
     printf("%d ",heap[i]);
   }
int max=get_Max();
   printf("\nThe element which is having the highest priority is %d: ",max);


   int min=get_Min();
      printf("\nThe element which is having the minimum priority is : %d",min);
   return 0;
}
```


21
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