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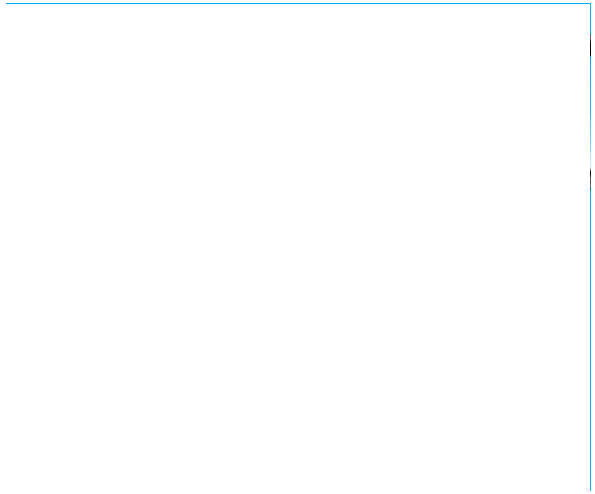
Binary Heap

A Binary Heap is a Binary Tree with followin

1) It's a complete tree (All levels are complete and the last level has all keys as left as possible). This property of Binary Heap makes them suitable to be stored in an array.

2) A Binary Heap is either Min Heap or Max Heap. In a Min Binary Heap, the key at root must be minimum among all keys present in Binary Heap. The same property must be recursively true for all nodes in Binary Tree. Max Binary Heap is similar to MinHeap.

Examples of Min Heap:



```
        10                      10
      /    \                  /    \
    20      100             15      30
```

```
    /                   /  \       /  \
  30                  40    50   100   40
```

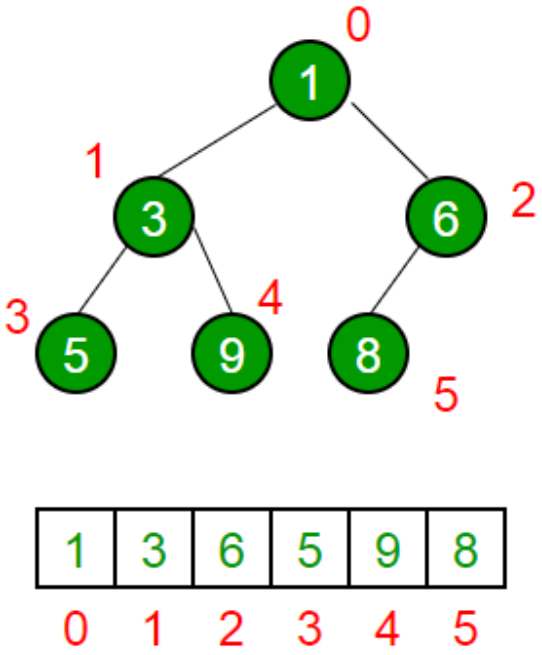
How is Binary Heap represented?

A Binary Heap is a Complete Binary Tree. A binary heap is typically represented as an array.

- The root element will be at Arr[0].
- Below table shows indexes of other nodes for the i^{th} node, i.e., Arr[i]:

Arr[(i-1)/2]	Returns the parent node
Arr[(2*i)+1]	Returns the left child node
Arr[(2*i)+2]	Returns the right child node

The traversal method use to achieve Array representation is **Level Order**



Please refer Array Representation Of Binary Heap for details.

Applications of Heaps:

1) Heap Sort: Heap Sort uses Binary Heap to sort an array in O(nLogn) time.

2) Priority Queue: Priority queues can be efficiently implemented using Binary Heap because it supports insert(), delete() and extractmax(), decreaseKey() operations in O(logn) time. Binomoial Heap and Fibonacci Heap are variations of Binary Heap. These variations perform union also efficiently.

3) Graph Algorithms: The priority queues are especially used in Graph Algorithms like Dijkstra's Shortest Path and Prim's Minimum Spanning Tree.

4) Many problems can be efficiently solved using Heaps. See following for example.

a) K'th Largest Element in an array.

b) Sort an almost sorted array/

c) Merge K Sorted Arrays.

Operations on Min Heap:

1) getMini(): It returns the root element of Min Heap. Time Complexity of this operation is O(1).

2) extractMin(): Removes the minimum element from MinHeap. Time Complexity of this Operation is O(Logn) as this operation needs to maintain the heap property (by calling heapify()) after removing root.

3) decreaseKey(): Decreases value of key. The time complexity of this operation is O(Logn). If the decreases key value of a node is greater than the parent of the node, then we don't need to do anything. Otherwise, we need to traverse up to fix the violated heap property.

4) insert(): Inserting a new key takes O(Logn) time. We add a new key at the end of the tree. IF new key is greater than its parent, then we don't need to do anything. Otherwise, we need to traverse up to fix the violated heap property.

5) delete(): Deleting a key also takes O(Logn) time. We replace the key to be deleted with minum infinite by calling decreaseKey(). After decreaseKey(), the minus infinite value must reach root, so we call extractMin() to remove the key.

Below is the implementation of basic heap operations.

```
// A C++ program to demonstrate common Binary Heap Operations
#include<iostream>
#include<climits>
using namespace std;

// Prototype of a utility function to swap two integers
void swap(int *x, int *y);

// A class for Min Heap
class MinHeap
{
    int *harr; // pointer to array of elements in heap
    int capacity; // maximum possible size of min heap
    int heap_size; // Current number of elements in min heap
public:
    // Constructor
    MinHeap(int capacity);

    // to heapify a subtree with the root at given index
    void MinHeapify(int );

    int parent(int i) { return (i-1)/2; }

    // to get index of left child of node at index i
    int left(int i) { return (2*i + 1); }

    // to get index of right child of node at index i
    int right(int i) { return (2*i + 2); }

    // to extract the root which is the minimum element
    int extractMin();
```

```
    // Decreases key value of key at index i to new_val
    void decreaseKey(int i, int new_val);

    // Returns the minimum key (key at root) from min heap
    int getMin() { return harr[0]; }

    // Deletes a key stored at index i
    void deleteKey(int i);

    // Inserts a new key 'k'
    void insertKey(int k);
};

// Constructor: Builds a heap from a given array a[] of given size
MinHeap::MinHeap(int cap)
{
    heap_size = 0;
    capacity = cap;
    harr = new int[cap];
}

// Inserts a new key 'k'
void MinHeap::insertKey(int k)
{
    if (heap_size == capacity)
    {
        cout << "\nOverflow: Could not insertKey\n";
        return;
    }

    // First insert the new key at the end
    heap_size++;
    int i = heap_size - 1;
    harr[i] = k;

    // Fix the min heap property if it is violated
    while (i != 0 && harr[parent(i)] > harr[i])
    {
       swap(&harr[i], &harr[parent(i)]);
       i = parent(i);
    }
}
```

```
// Decreases value of key at index 'i' to new_val.  It is assumed that
// new_val is smaller than harr[i].
void MinHeap::decreaseKey(int i, int new_val)
{
    harr[i] = new_val;
    while (i != 0 && harr[parent(i)] > harr[i])
    {
       swap(&harr[i], &harr[parent(i)]);
       i = parent(i);
    }
}

// Method to remove minimum element (or root) from min heap
int MinHeap::extractMin()
{
    if (heap_size <= 0)
        return INT_MAX;
    if (heap_size == 1)
    {
        heap_size--;
        return harr[0];
    }

    // Store the minimum value, and remove it from heap
    int root = harr[0];
    harr[0] = harr[heap_size-1];
    heap_size--;
    MinHeapify(0);

    return root;
}


// This function deletes key at index i. It first reduced value to minus
// infinite, then calls extractMin()
void MinHeap::deleteKey(int i)
{
    decreaseKey(i, INT_MIN);
    extractMin();
}
```

```
// A recursive method to heapify a subtree with the root at given index
// This method assumes that the subtrees are already heapified
void MinHeap::MinHeapify(int i)
{
    int l = left(i);
    int r = right(i);
    int smallest = i;
    if (l < heap_size && harr[l] < harr[i])
        smallest = l;
    if (r < heap_size && harr[r] < harr[smallest])
        smallest = r;
    if (smallest != i)
    {
        swap(&harr[i], &harr[smallest]);
        MinHeapify(smallest);
    }
}

// A utility function to swap two elements
void swap(int *x, int *y)
{
    int temp = *x;
    *x = *y;
    *y = temp;
}

// Driver program to test above functions
int main()
{
    MinHeap h(11);
    h.insertKey(3);
    h.insertKey(2);
    h.deleteKey(1);
    h.insertKey(15);
    h.insertKey(5);
    h.insertKey(4);
    h.insertKey(45);
    cout << h.extractMin() << " ";
    cout << h.getMin() << " ";
    h.decreaseKey(2, 1);
    cout << h.getMin();
    return 0;
```

```
}
```

Python

```python
# A Python program to demonstrate common binary heap operations

# Import the heap functions from python library
from heapq import heappush, heappop, heapify

# heappop - pop and return the smallest element from heap
# heappush - push the value item onto the heap, maintaining
#             heap invarient
# heapify - transform list into heap, in place, in linear time

# A class for Min Heap
class MinHeap:

    # Constructor to initialize a heap
    def __init__(self):
        self.heap = []

    def parent(self, i):
        return (i-1)/2

    # Inserts a new key 'k'
    def insertKey(self, k):
        heappush(self.heap, k)

    # Decrease value of key at index 'i' to new_val
    # It is assumed that new_val is smaller than heap[i]
    def decreaseKey(self, i, new_val):
        self.heap[i]  = new_val
        while(i != 0 and self.heap[self.parent(i)] > self.heap[i]):
            # Swap heap[i] with heap[parent(i)]
            self.heap[i] , self.heap[self.parent(i)] = (
            self.heap[self.parent(i)], self.heap[i])

    # Method to remove minium element from min heap
    def extractMin(self):
```

```
        return heappop(self.heap)

    # This functon deletes key at index i. It first reduces
    # value to minus infinite and then calls extractMin()
    def deleteKey(self, i):
        self.decreaseKey(i, float("-inf"))
        self.extractMin()

    # Get the minimum element from the heap
    def getMin(self):
        return self.heap[0]

# Driver pgoratm to test above function
heapObj = MinHeap()
heapObj.insertKey(3)
heapObj.insertKey(2)
heapObj.deleteKey(1)
heapObj.insertKey(15)
heapObj.insertKey(5)
heapObj.insertKey(4)
heapObj.insertKey(45)

print heapObj.extractMin(),
print heapObj.getMin(),
heapObj.decreaseKey(2, 1)
print heapObj.getMin()

# This code is contributed by Nikhil Kumar Singh(nickzuck_007)
```

Output:

```
2 4 1
```

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