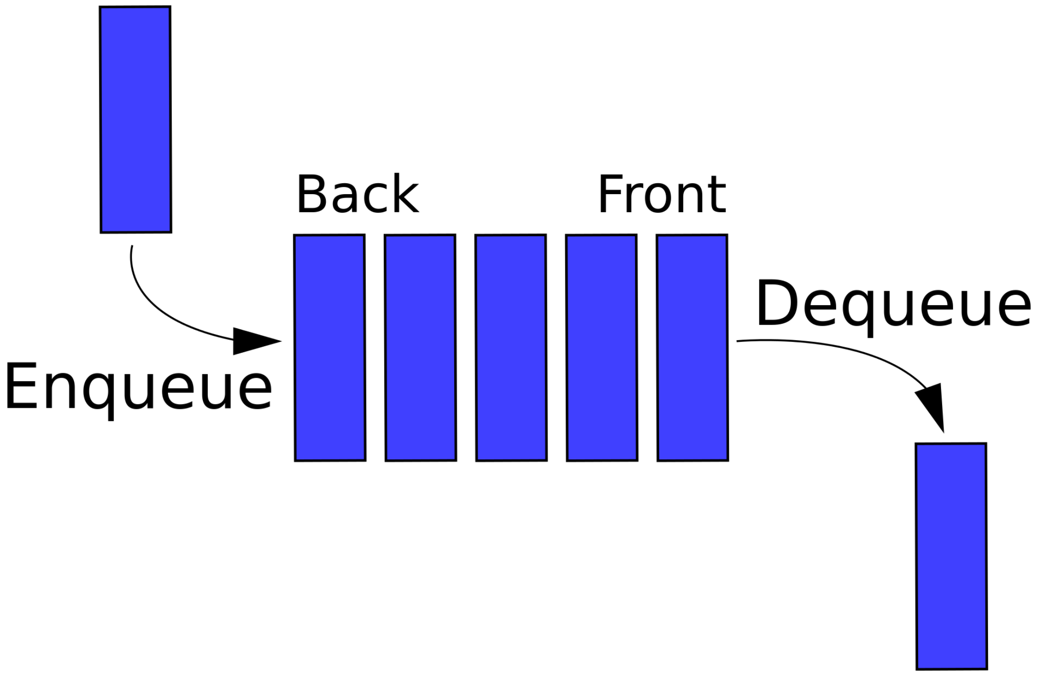
QUEUES, PRIORITY QUEUES (HEAPS)

Problem Solving with Computers-II

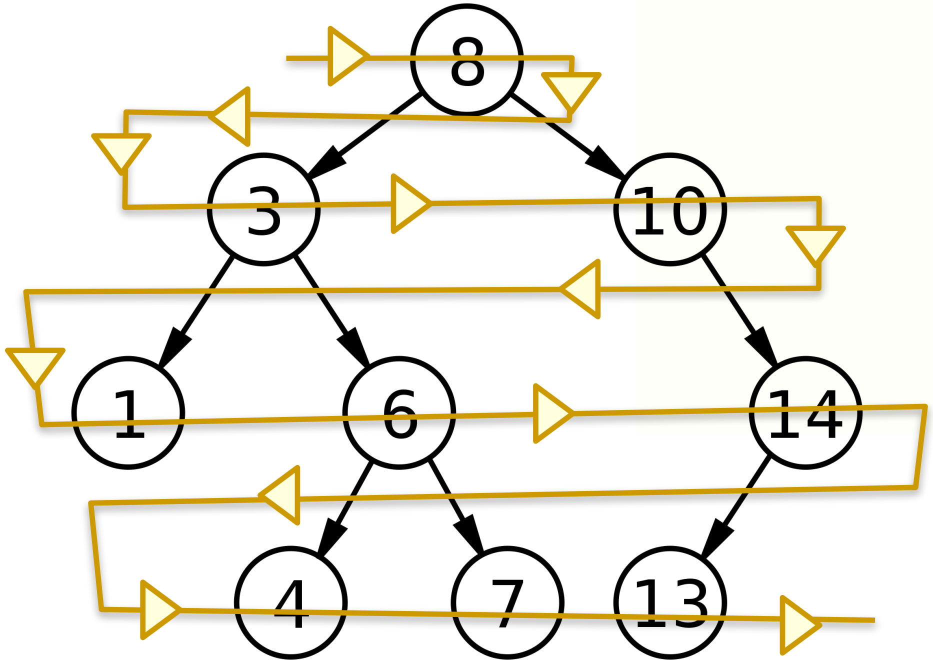
Queues

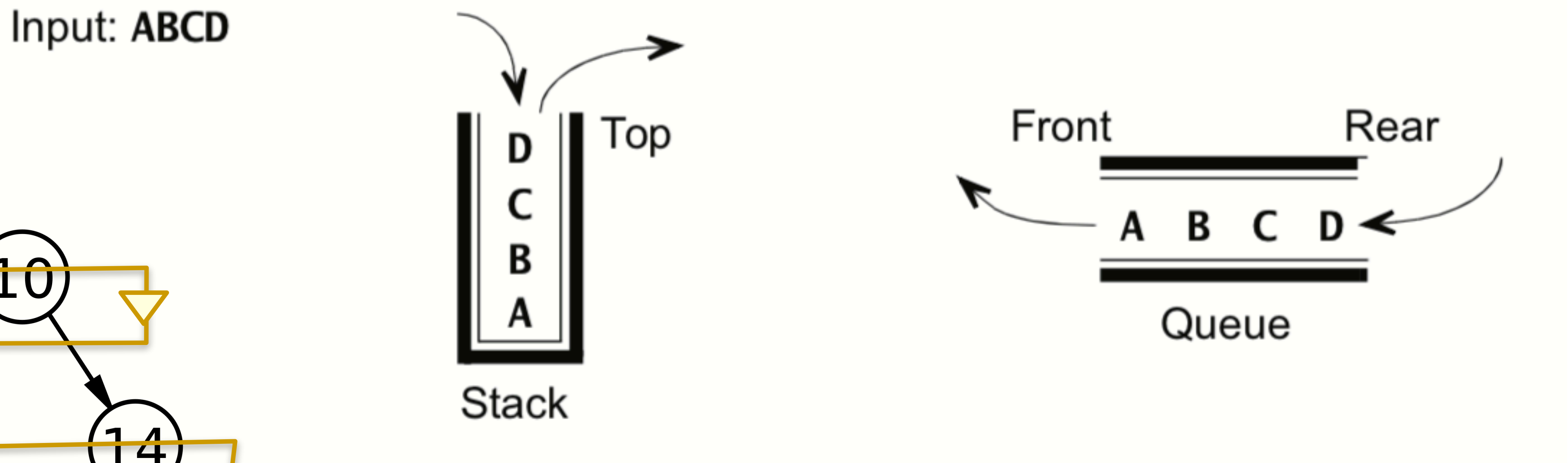
- A queue is a data structure very similar to a stack
  - Stacks: last in, first out (LIFO)
  - Queues: first in, first out (FIFO)
    - remember that “queue” is just British English for “line (of people)”
- Queue operations:
  - Push—add to the **end** of the queue
  - Pop—remove from the **front**
  - Front—get the element at the **front**
  - Empty—check if the queue is empty



Example Applications of Queues

- Example 1: palindrome checking with a stack and a queue
- Example 2: breadth first traversal of a binary search tree





Heaps

- Clarification
  - *heap*, the data structure is not related to *heap,* the region of memory
- What are the operations supported?
- What are the running times?

Heaps

	Min-Heaps	Max-Heap	BST
Insert :			
Min:			
Delete Min:			
Max			
Delete Max			

Applications:

- Efficient sort
- Finding the median of a sequence of numbers
- Compression codes

Choose heap if you are doing repeated insert/delete/(min OR max) operations

std::priority_queue (STL's version of heap)

A C++ `priority_queue` is a generic container, and can store any data type on which an ordering can be defined: for example `ints`, `structs (Card)`, pointers etc.

#include <queue>

```
priority_queue<int> pq;
```

Methods:

```
* push()   //insert
* pop()    //delete max priority item
* top()    //get max priority item
* empty()  //returns true if the priority queue is empty
```

- You can extract object of highest priority in O(log N)
- To determine priority: objects in a priority queue must be comparable to each other

STL Heap implementation: Priority Queues in C++

What is the output of this code?

```
priority_queue<int> pq;
pq.push(10);
pq.push(2);
pq.push(80);
cout<<pq.top();
pq.pop();
cout<<pq.top();
pq.pop();
cout<<pq.top();
pq.pop();
```

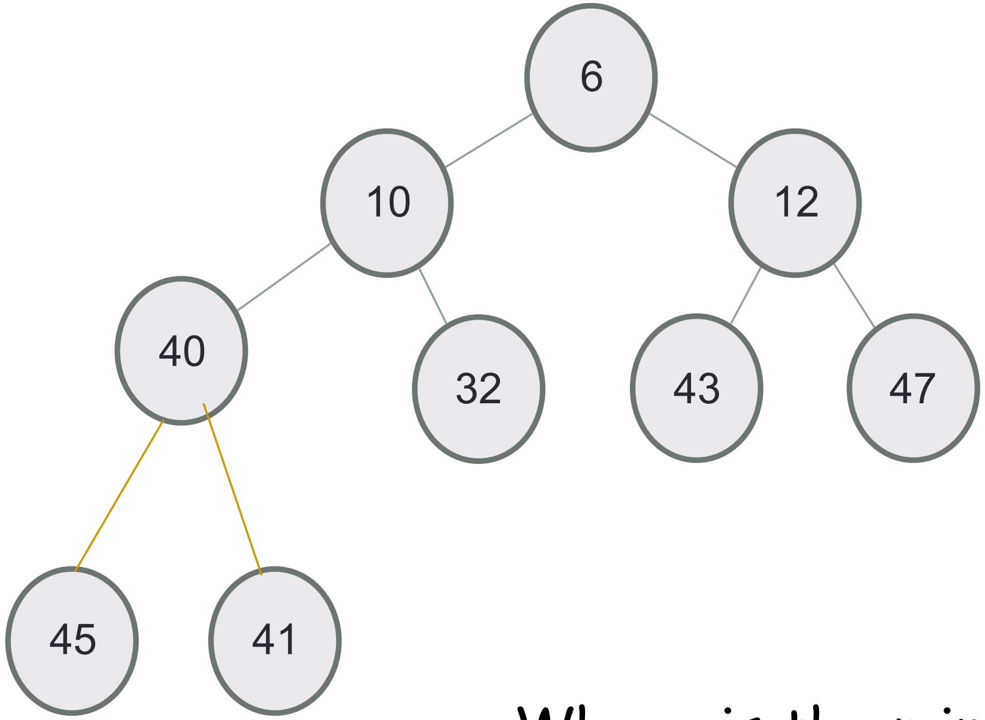
A. 10 2 80
B. 2 10 80
C. 80 10 2
D. 80 2 10
E. None of the above

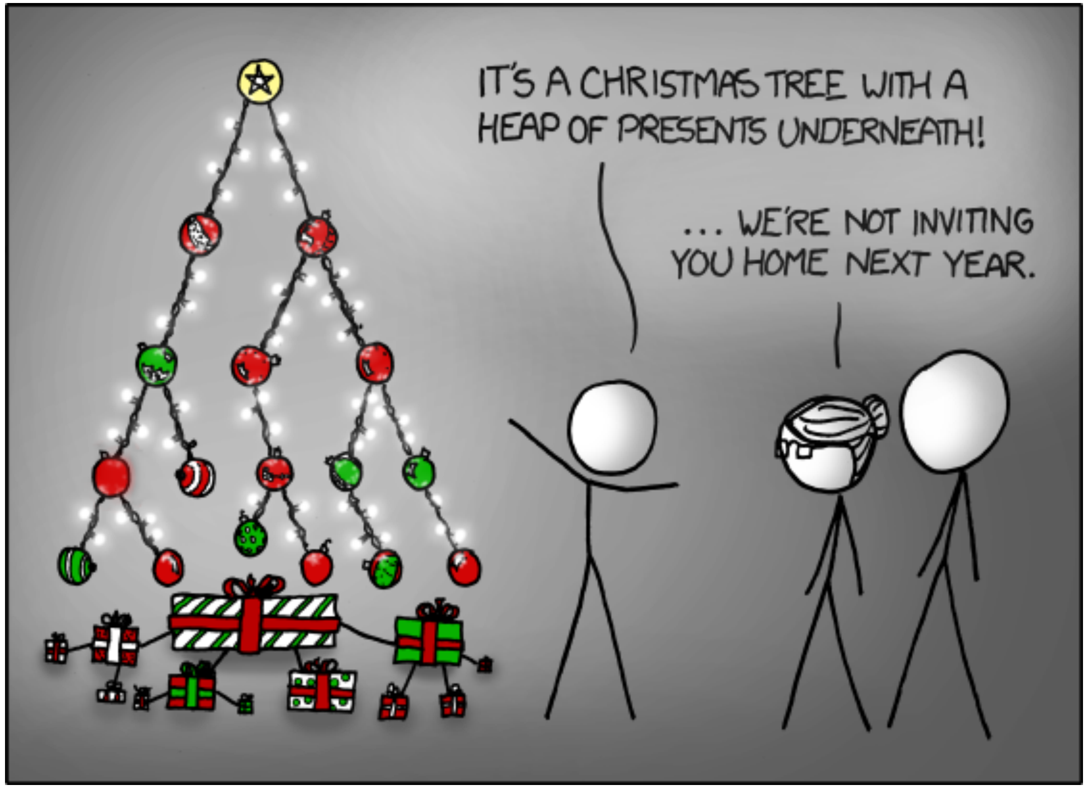
Heaps as binary trees

- **Rooted binary tree that is as complete as possible**
- **In a min-Heap, each node satisfies the following heap property:**

key(x)<= key(children of x)

Min Heap with 9 nodes



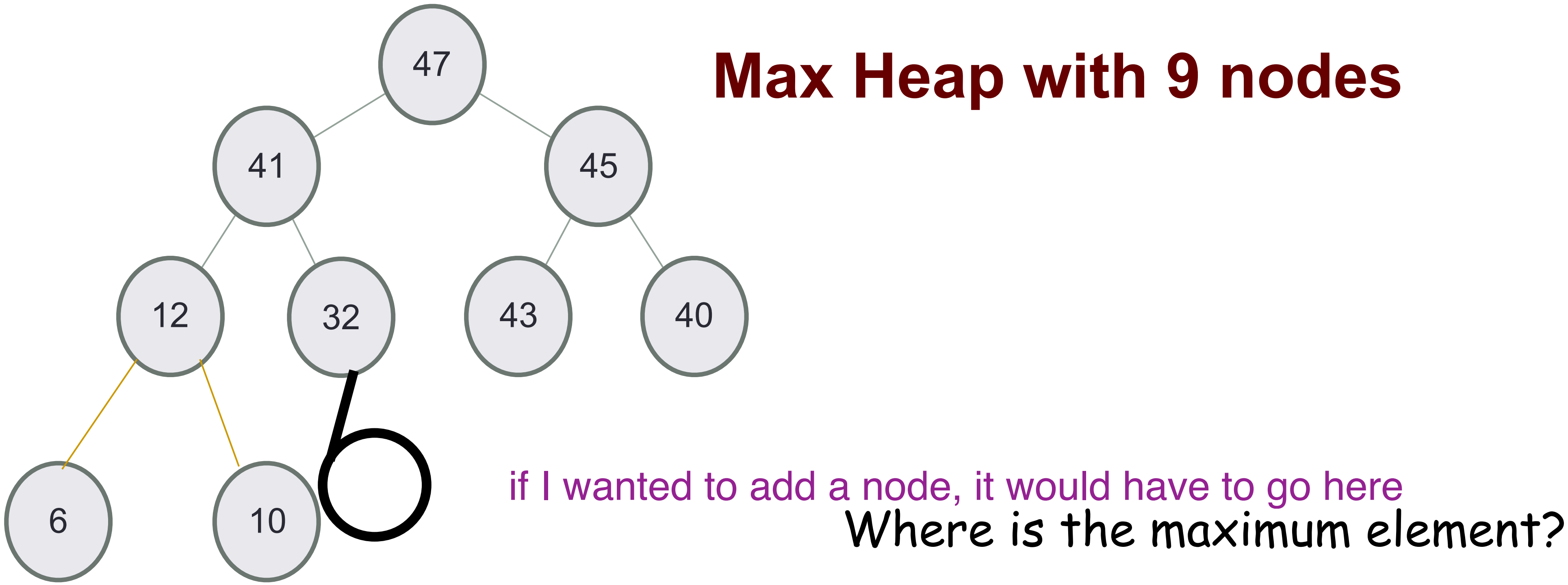


Where is the minimum element?

Heaps as binary trees

- **Rooted binary tree that is as complete as possible**
- **In a max-Heap, each node satisfies the following heap property:**

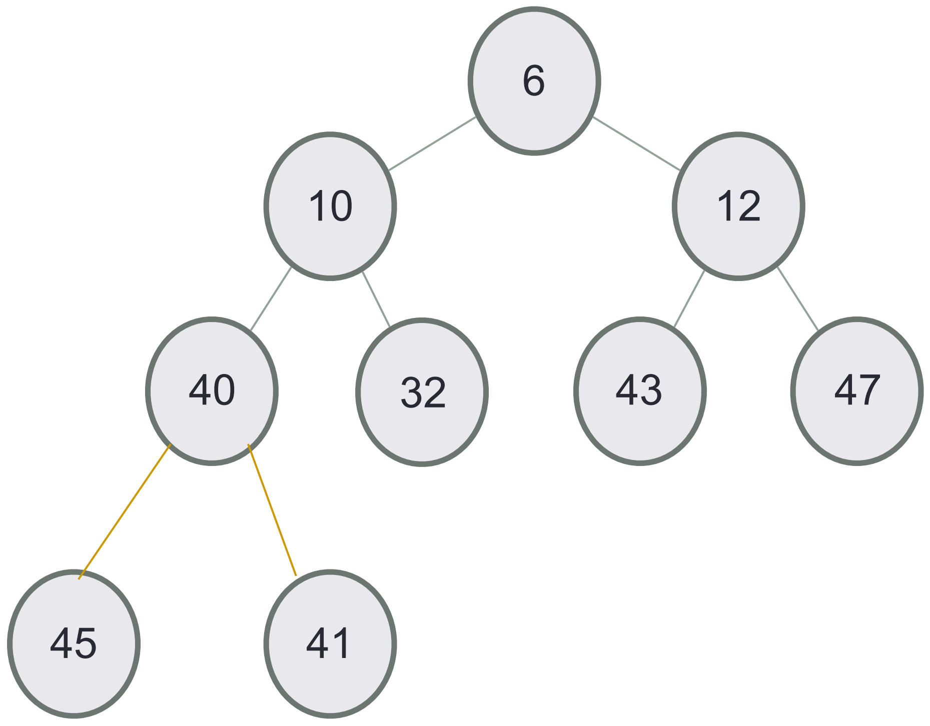
  key(x)>= key(children of x)



Identifying heaps

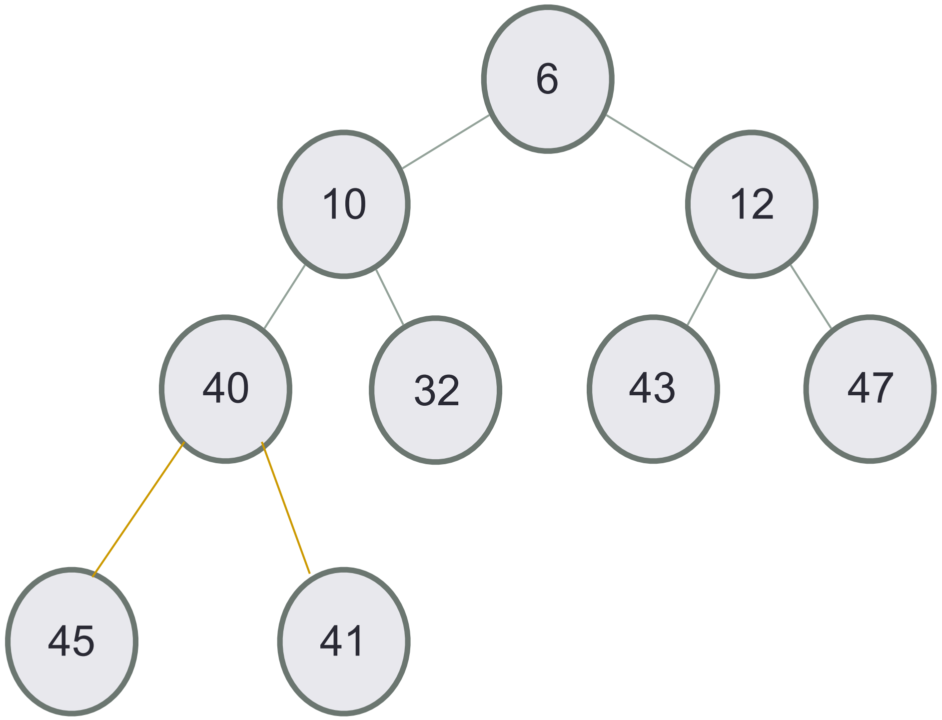
Starting with the following min-Heap which of the following operations will result in something that is NOT a min Heap

A. Swap the nodes 40 and 32
B. Swap the nodes 32 and 43
C. Swap the nodes 43 and 40
D. Insert 50 as the left child of 45
E. C&D



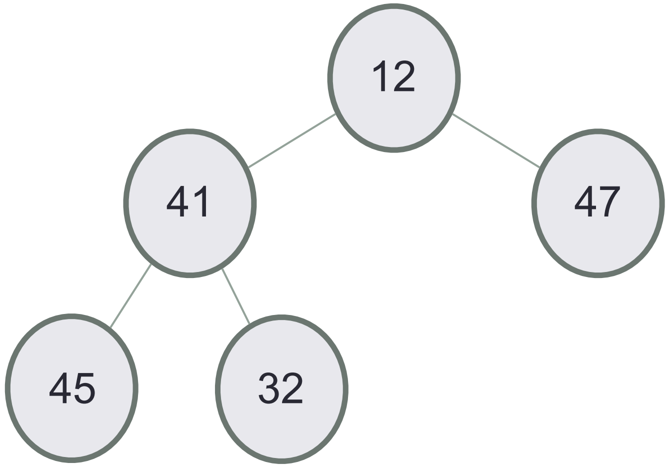
Structure: Complete binary tree

A heap is a complete binary tree: Each level is as full as possible. Nodes on the bottom level are placed as far left as possible

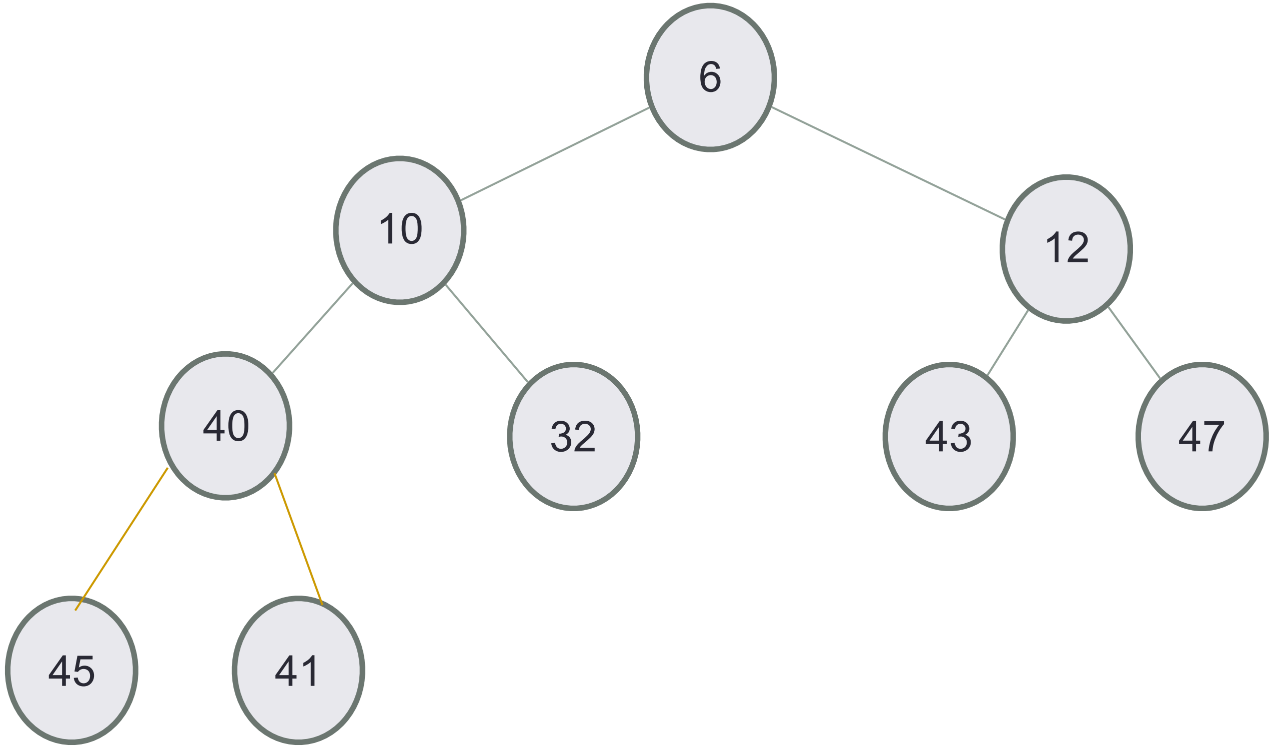


Insert 50 into a heap

- **Insert key(x) in the first open slot at the last level of tree (going from left to right)**
- **If the heap property is not violated - Done**
- **Else: while(key(parent(x))>key(x)) swap the key(x) with key(parent(x))**

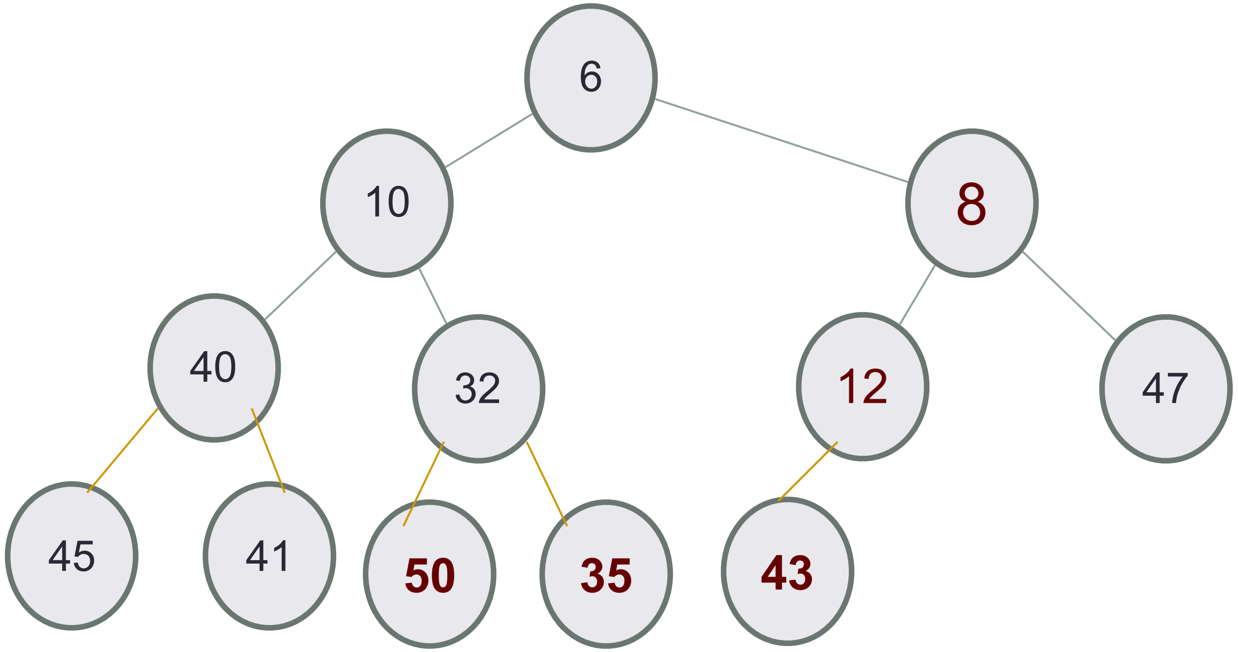


Insert 50, then 35, then 8



Delete min

- **Replace the root with the rightmost node at the last level**
- **"Bubble down"- swap node with one of the children until the heap property is restored**

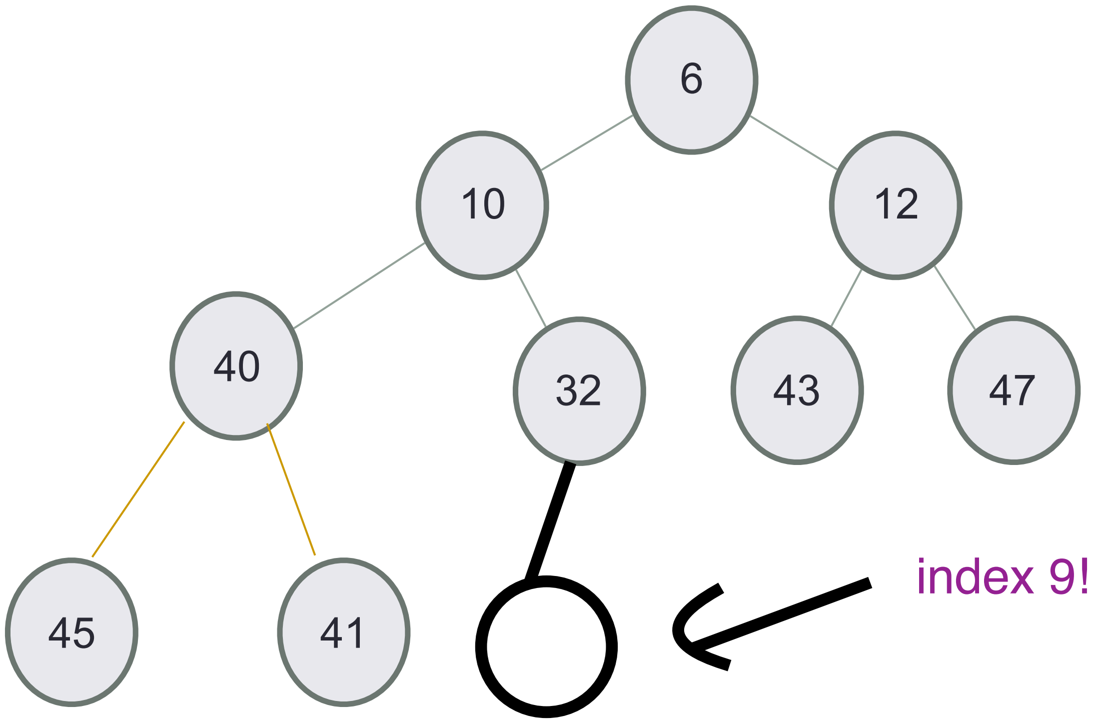


Under the hood of heaps

- An efficient way of implementing heaps is using vectors
- Although we think of heaps as trees, the entire tree can be efficiently represented as a vector!!

Implementing heaps using an array or vector

Value	6	10	12	40	32	43	47	45	41	
Index	0	1	2	3	4	5	6	7	8	



Using vector as the internal data structure of the heap has some advantages:

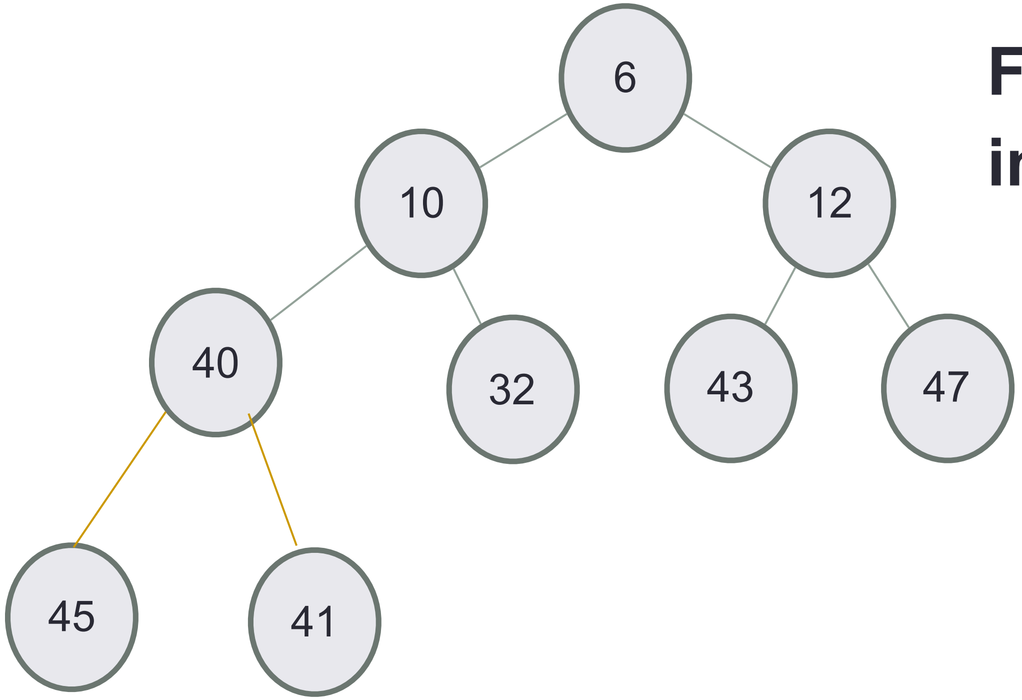
- **More space efficient than trees**
- **Easier to insert nodes into the heap**

Insert into a heap

- **Insert key(x) in the first open slot at the last level of tree (going from left to right)**
- **If the heap property is not violated - Done**
- **Else….**

Insert the elements {12, 41, 47, 45, 32} in a min-Heap using the vector representation of the heap

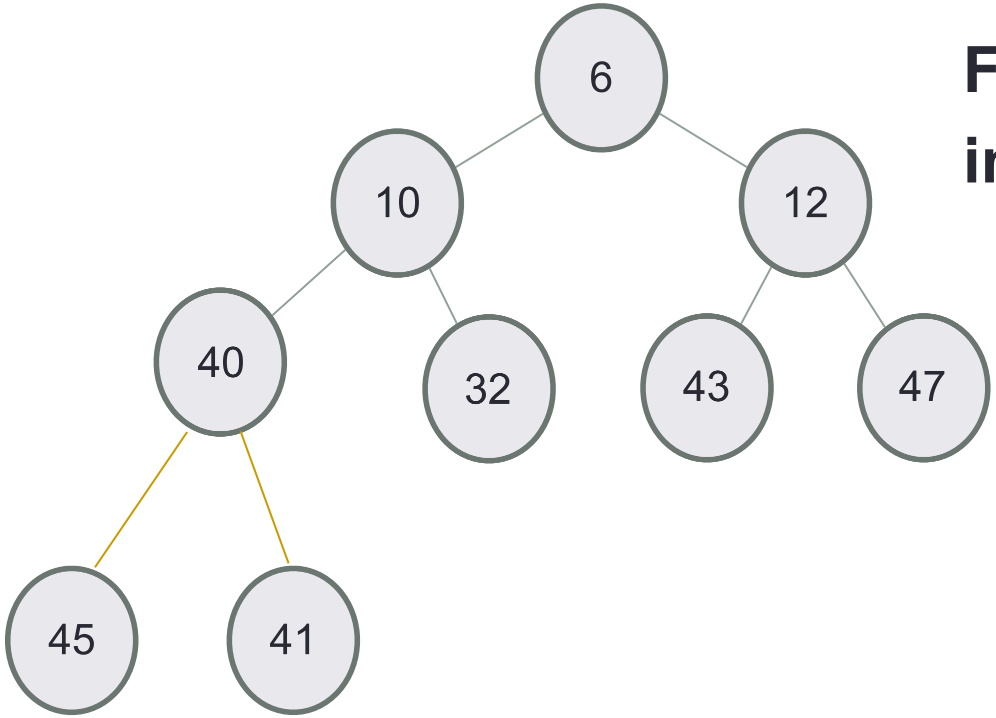
Finding the "parent" of a "node" in the vector representation



For a node at index i, index of the parent is int((i-1)/2)

Value	6	10	12	40	32	43	47	45	41	
Index	0	1	2	3	4	5	6	7	8	

Insert 50, then 35



For a node at index i, index of the parent is int(i-1/2)

Value	6	10	12	40	32	43	47	45	41	
Index	0	1	2	3	4	5	6	7	8	

Insert 8 into a heap

Value	6	10	12	40	32	43	47	45	41	50	35
Index	0	1	2	3	4	5	6	7	8	9	10

After inserting 8, which node is the parent of 8 ?

A. Node 6

B. Node 12

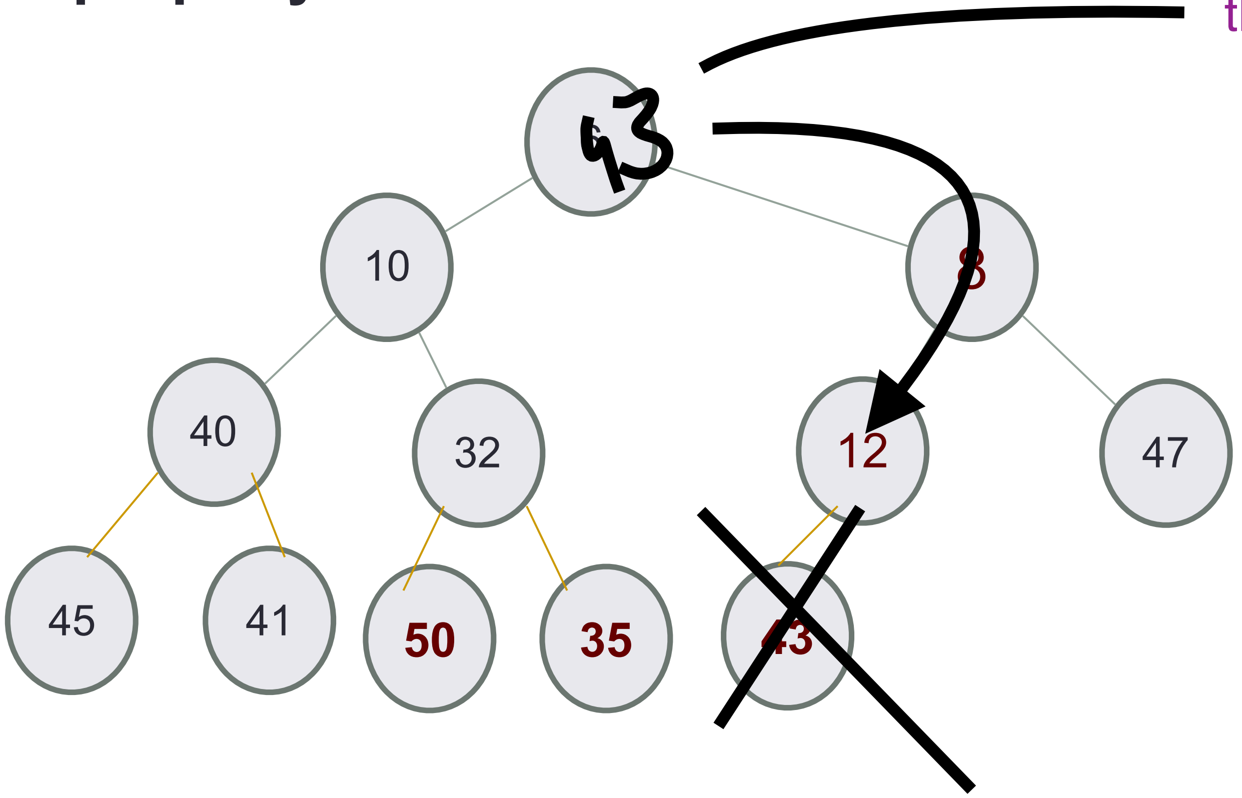
C. Node 43

D. None - Node 8 will be the root

Delete min

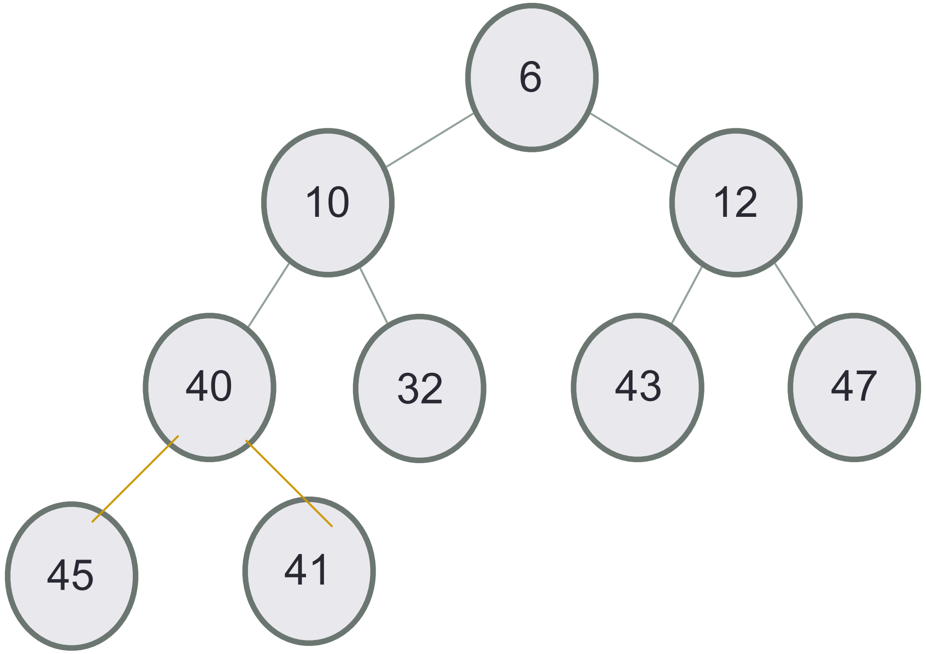
- **Replace the root with the rightmost node at the last level**
- **“Bubble down”- swap node with one of the children until the heap property is restored**

this is index 0. I need the children’s indices now!



Traversing down the tree

Value	6	10	12	40	32	43	47	45	41	
Index	0	1	2	3	4	5	6	7	8	



For a node at index i, what is the index of the left and right children?

A. (2*i, 2*i+1)
B. (2*i+1, 2*i+2)
C. (log(i), log(i)+1)
D. None of the above