YAQDS: Yet another …

- What is the dequeue policy for a Queue?
  - Why do we implement Queue with LinkedList
    - Interface and class in Java 5 `java.util`
  - Can we remove an element other than first?

- How did queue help in word-ladder/shortest path?
  - First item enqueued/added is the one we want
  - What if different element is "best"?

- PriorityQueue is like a queue, but different dequeue policy
  - Best item is dequeued, queue manages itself to ensure operations are efficient

Why use PriorityQueue?

- Implementation of several algorithms facilitated by using pq, efficient implementation helps ensure algorithm efficiency
  - Mapquest, Googlemap, shortest path
    - How is this like word-ladder? How different?
  - Connecting all outlets in a house with minimal wiring

- Data compression facilitated by using priority queue
  - Alltime best assignment in a Compsci 100 course?
    - Subject to debate, of course
  - From A-Z, soup-to-nuts, bits to abstractions

Data Compression

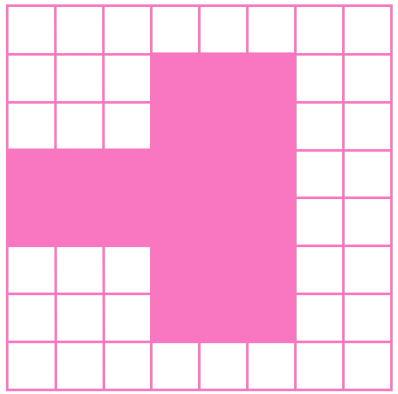
- Compression is a high-profile application
  - .zip, .mp3, .jpg, .gif, .gz, …
  - What property of MP3 was a significant factor in what made Napster work (why did Napster ultimately fail?)

- Why do we care?
  - Secondary storage capacity doubles every year
  - Disk space fills up quickly on every computer system
  - More data to compress than ever before

More on Compression

- What's the difference between compression techniques?
  - .mp3 files and .zip files?
  - .gif and .jpg?
  - Lossless and lossy
- Is it possible to compress (lossless) every file? Why?
- Lossy methods
  - Good for pictures, video, and audio (JPEG, MPEG, etc.)
- Lossless methods
  - Run-length encoding, Huffman, LZW, ...

11 3 5 3 2 6 2 6 5 3 5 3 5 3 10



Priority Queue

- Compression motivates the study of the ADT *priority queue*
  - Supports two basic operations
    - `add/insert` -- an element into the priority queue
    - `remove/delete` – the *minimal* element from the priority queue
  - Implementations may allow `getmin/peek` separate from delete
    - Analogous to top/pop, peek/dequeue in stacks, queues

- See PQDemo.java,
  - code below sorts, complexity?

```
Scanner s;
PriorityQueue<String> pq =
        new PriorityQueue<String>();
while (s.hasNext()) pq.add(s.next());
while (pq.size() > 0) {
     System.out.println(pq.remove());
}
```

Priority Queue implementations

- Implementing priority queues: average and worst case

	Insert average	Getmin (delete)	Insert worst	Getmin (delete)
Unsorted vector				
Sorted vector				
Search tree				
Balanced tree				
Heap				

- Heap has O(1) find-min (no delete) and O(n) build heap

Priority Queue implementations

- Implementing priority queues: average and worst case

	Insert average	Getmin (delete)	Insert worst	Getmin (delete)
Unsorted vector	O(1)	O(n)	O(1)	O(n)
Sorted vector				
Search tree				
Balanced tree				
Heap				

- Heap has O(1) find-min (no delete) and O(n) build heap

Priority Queue implementations

- Implementing priority queues: average and worst case

	Insert average	Getmin (delete)	Insert worst	Getmin (delete)
Unsorted vector	O(1)	O(n)	O(1)	O(n)
Sorted vector	O(n)	O(1)	O(n)	O(1)
Search tree				
Balanced tree				
Heap				

- Heap has O(1) find-min (no delete) and O(n) build heap

Priority Queue implementations

- Implementing priority queues: average and worst case

	Insert average	Getmin (delete)	Insert worst	Getmin (delete)
Unsorted vector	O(1)	O(n)	O(1)	O(n)
Sorted vector	O(n)	O(1)	O(n)	O(1)
Search tree	log n	log n	O(n)	O(n)
Balanced tree				
Heap				

- Heap has O(1) find-min (no delete) and O(n) build heap

Priority Queue implementations

- Implementing priority queues: average and worst case

	Insert average	Getmin (delete)	Insert worst	Getmin (delete)
Unsorted vector	O(1)	O(n)	O(1)	O(n)
Sorted vector	O(n)	O(1)	O(n)	O(1)
Search tree	log n	log n	O(n)	O(n)
Balanced tree	log n	log n	log n	log n
Heap				

- Heap has O(1) find-min (no delete) and O(n) build heap

Priority Queue implementations

- Implementing priority queues: average and worst case

	Insert average	Getmin (delete)	Insert worst	Getmin (delete)
Unsorted vector	O(1)	O(n)	O(1)	O(n)
Sorted vector	O(n)	O(1)	O(n)	O(1)
Search tree	log n	log n	O(n)	O(n)
Balanced tree	log n	log n	log n	log n
Heap	O(1)	log n	log n	log n

- Heap has O(1) find-min (no delete) and O(n) build heap

PriorityQueue.java (Java 5)

- What about objects inserted into pq?
  - For "min-heap", what properties must inserted objects have, e.g., insert non-comparable?
  - Change what minimal means?
  - Implementation uses *heap*

- If we use a Comparator for comparing entries we can make a min-heap act like a max-heap, see PQDemo
  - Where is class Comparator declaration? How used?
  - What if we didn't know about Collections.reverseOrder?
    - How do we make this ourselves?

Sorting w/o `Collections.sort(...)`

```
public static void sort(ArrayList<String> a)
{
  PriorityQueue<String> pq =
                new PriorityQueue<String>();
  pq.addAll(a);
  for(int k=0; k < a.size(); k++) a.set(k,pq.remove());
}
```

- How does this work, regardless of pq implementation?
- What is the complexity of this method?
  - add `O(1)`, remove `O(log n)`? If add `O(log n)`?
  - heapsort uses array as the priority queue rather than separate pq object.
  - From a big-Oh perspective no difference: *`O(n log n)`*
    - Is there a difference? What's hidden with O notation?

Priority Queue implementation

- `PriorityQueue` uses heaps, fast and reasonably simple
  - Why not use inheritance hierarchy as was used with Map?
  - Trade-offs when using HashMap and TreeMap:
    - Time, space
    - Ordering properties, e.g., what does TreeMap support?
- Changing method of comparison when calculating priority?
  - Create object to replace, or in lieu of `compareTo`
    - `Comparable` interface compares `this` to passed object
    - `Comparator` interface compares two passed objects
  - Both comparison methods: `compareTo()` and `compare()`
    - Compare two objects (parameters or self and parameter)
    - Returns –1, 0, +1 depending on <, ==, >

Creating Heaps

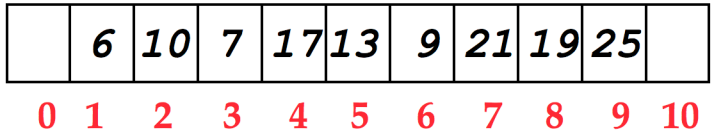
- Heap is an array-based implementation of a binary tree used for implementing priority queues, supports:
  - add/insert, peek/getmin, remove/deletemin, O(???)

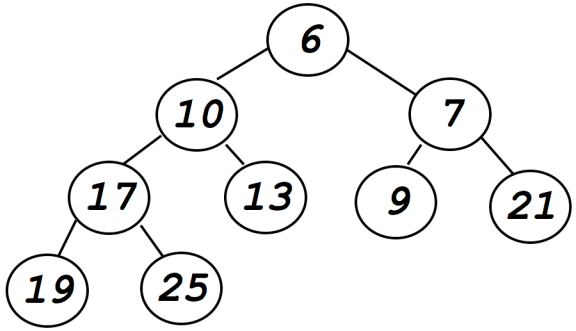
- Using array minimizes storage (no explicit pointers), faster too --- children are located by index/position in array

- Heap is a binary tree with *shape* property, *heap/value* property
  - shape: tree filled at all levels (except perhaps last) and filled left-to-right (complete binary tree)
  - each node has value smaller than both children

Array-based heap

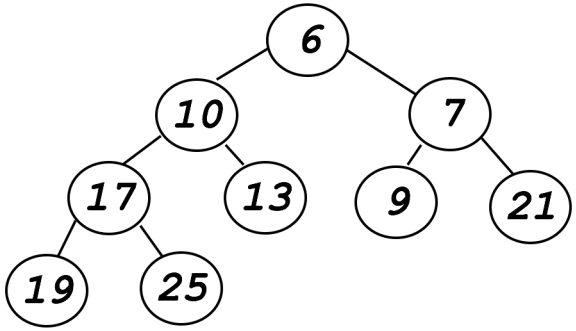
- store "node values" in array beginning at index 1
- for node with index k
  - left child: index `2*k`
  - right child: index `2*k+1`





- why is this conducive for maintaining heap shape?
- what about heap property?
- is the heap a search tree?
- where is minimal node?
- where are nodes added? deleted?

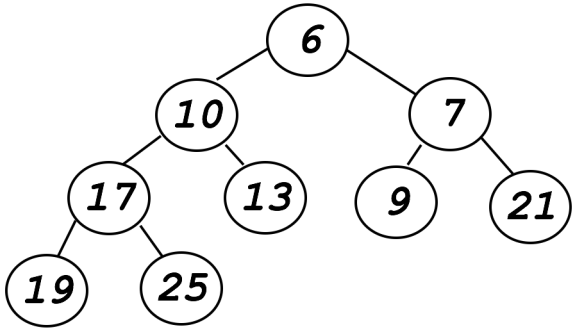
Thinking about heaps



	6	10	7	17	13	9	21	19	25	
0	1	2	3	4	5	6	7	8	9	10

Thinking about heaps

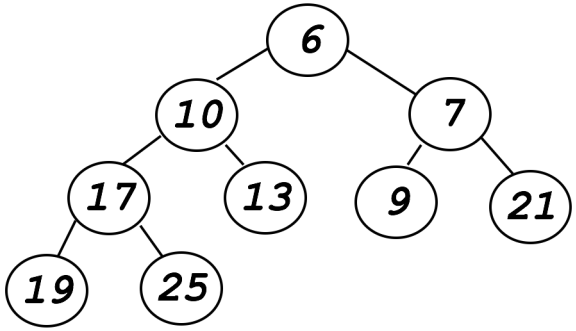
- Where is minimal element?



	6	10	7	17	13	9	21	19	25	
0	1	2	3	4	5	6	7	8	9	10

Thinking about heaps

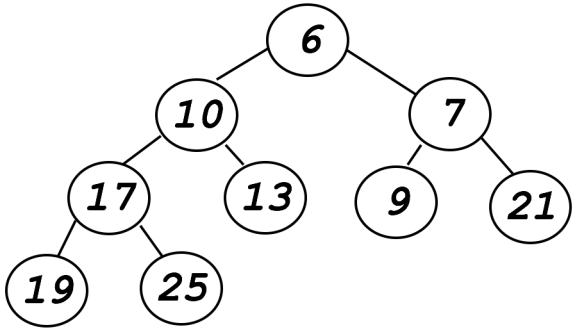
- **Where is minimal element?**
  - **Root, why?**

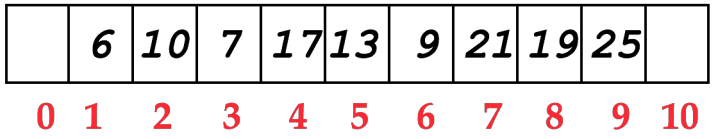


	6	10	7	17	13	9	21	19	25	
0	1	2	3	4	5	6	7	8	9	10

Thinking about heaps

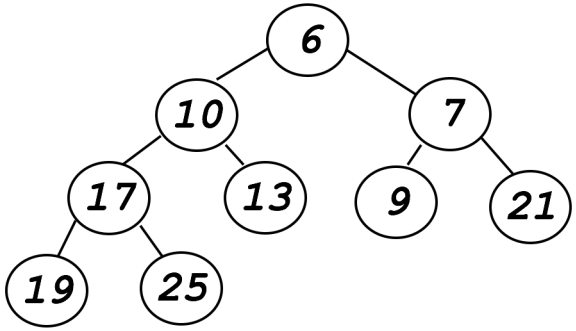
- Where is minimal element?
  - Root, why?
- Where is maximal element?

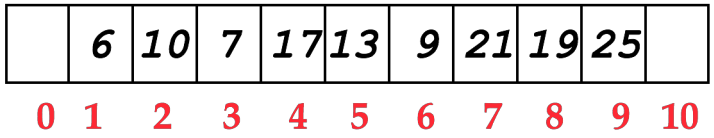




Thinking about heaps

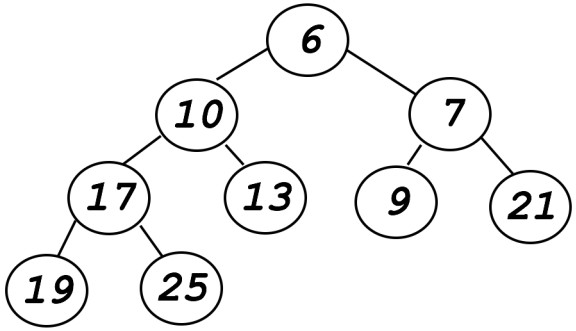
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?

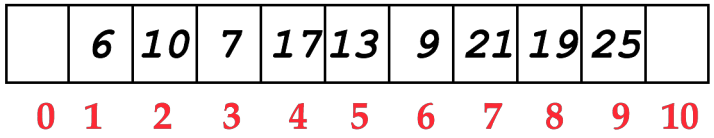




Thinking about heaps

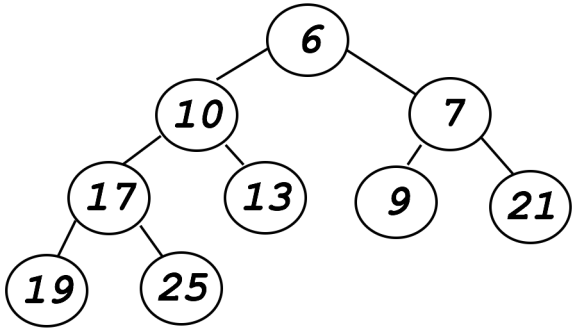
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?
- How many leaves are there in an N-node heap (big-Oh)?

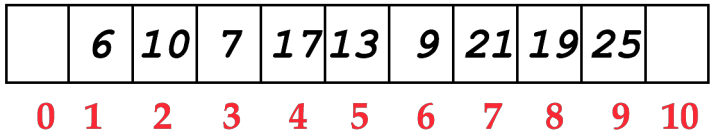




Thinking about heaps

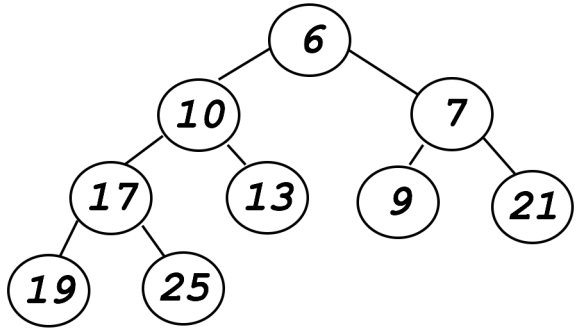
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?
- How many leaves are there in an N-node heap (big-Oh)?
  - O(n), but exact?

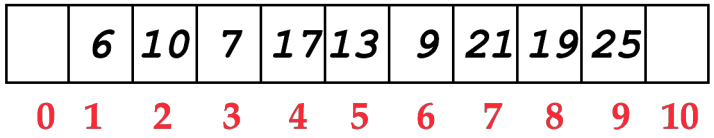




Thinking about heaps

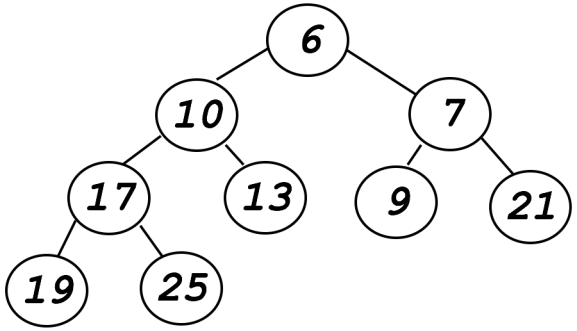
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?
- How many leaves are there in an N-node heap (big-Oh)?
  - O(n), but exact?
- What is complexity of find max in a minheap? Why?

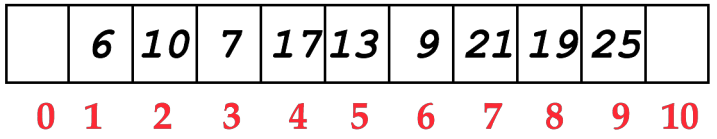




Thinking about heaps

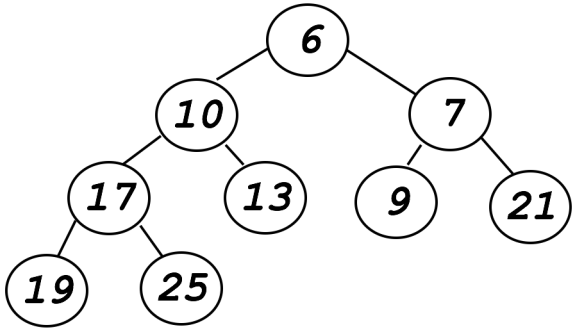
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?
- How many leaves are there in an N-node heap (big-Oh)?
  - O(n), but exact?
- What is complexity of find max in a minheap? Why?
  - O(n), but ½ N?





Thinking about heaps

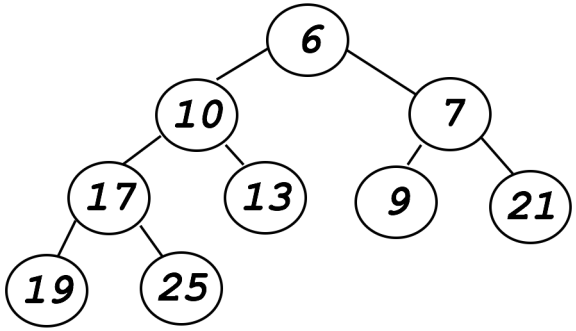
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?
- How many leaves are there in an N-node heap (big-Oh)?
  - O(n), but exact?
- What is complexity of find max in a minheap? Why?
  - O(n), but ½ N?
- Where is second smallest element? Why?

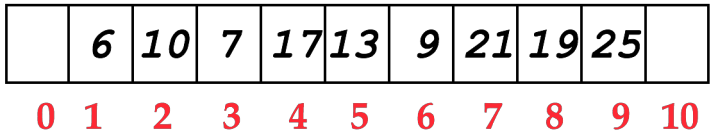


	6	10	7	17	13	9	21	19	25	
0	1	2	3	4	5	6	7	8	9	10

Thinking about heaps

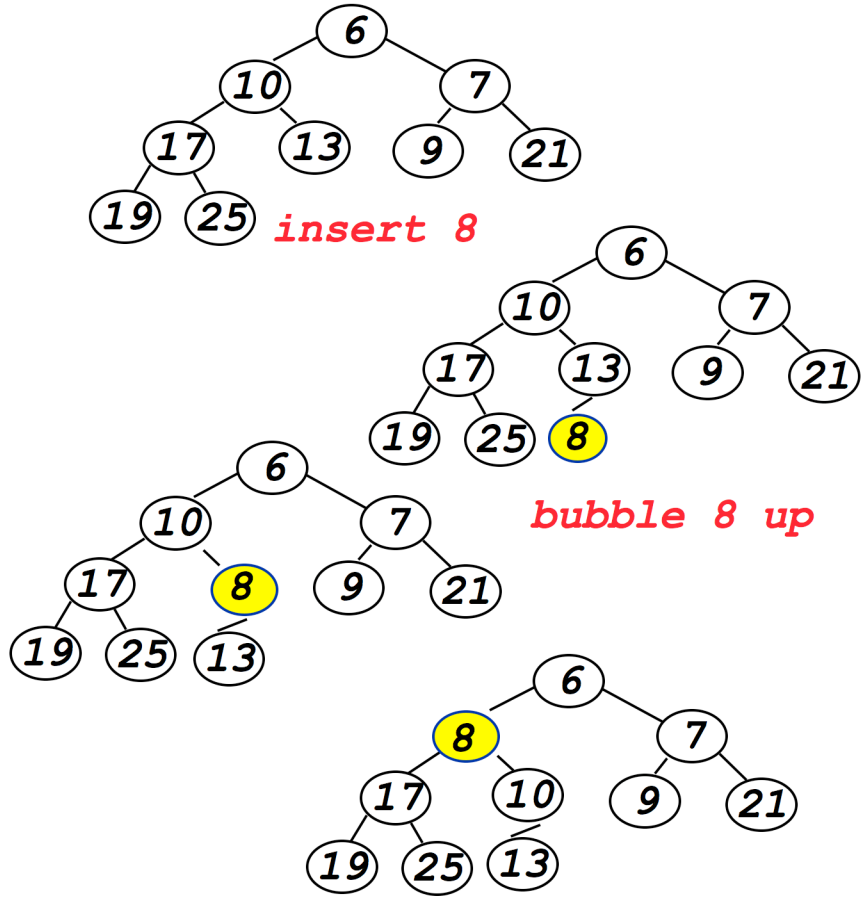
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?
- How many leaves are there in an N-node heap (big-Oh)?
  - O(n), but exact?
- What is complexity of find max in a minheap? Why?
  - O(n), but ½ N?
- Where is second smallest element? Why?
  - Near root?



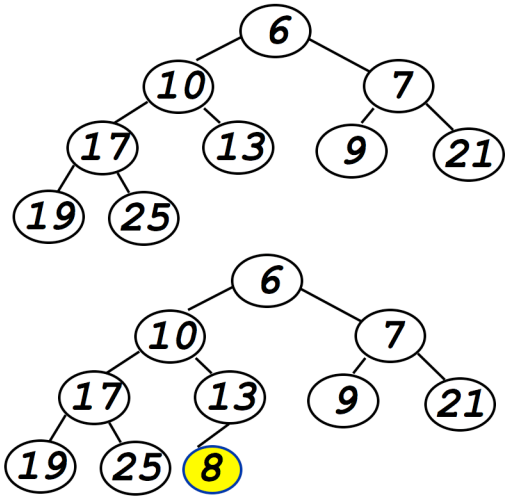


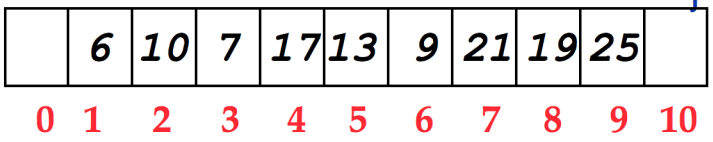
Adding values to heap

- to maintain heap shape, must add new value in left-to-right order of last level
  - could violate *heap property*
  - move value "up" if too small
- change places with parent if heap property violated
  - stop when parent is smaller
  - stop when root is reached
- pull parent down, swapping isn't necessary (optimization)



Adding values, details (pseudocode)





array myList

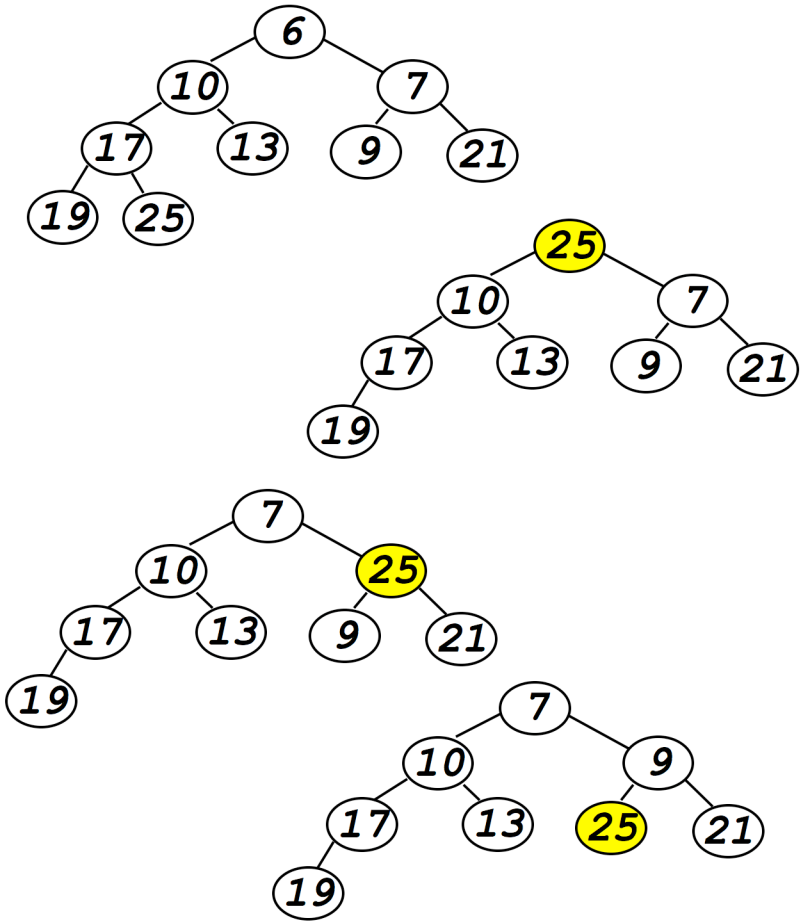
```
void add(Object elt)
{
  // add elt to heap in myList
  myList.add(elt);
  int loc = myList.size()-1;

  while (1 < loc &&
         elt < myList.get(loc/2)){
   myList.set(loc,myList.get(loc/2));
   loc = loc/2; // go to parent
  }
  // what's true here?

  myList.set(loc,elt);
}
```

Removing minimal element

- Where is minimal element?
  - If we remove it, what changes, shape/property?
- How can we maintain shape?
  - "last" element moves to root
  - What property is violated?
- After moving last element, subtrees of root are heaps, why?
  - Move root down (pull child up) does it matter where?
- When can we stop "re-heaping"?
  - Less than both children
  - Reach a leaf



Anita Borg 1949-2003

- "Dr. Anita Borg tenaciously envisioned and set about to change the world for women and for technology. … she fought tirelessly for the development technology with positive social and human impact."
- "Anita Borg sought to revolutionize the world and the way we think about technology and its impact on our lives."
- Founded Systers in 1987, http://www.iwt.org in 1997