YAQ, YAQ, haha! (Yet Another Queue)

- What is the dequeue policy for a Queue?
  - Why do we implement Queue with LinkedList
    - Interface and class in `java.util`
  - Can we remove an element other than first?
- How does queue help word-ladder/shortest path?
  - First item enqueued/added is the one we want
  - What if different element is "best"?
- PriorityQueue has a different dequeue policy
  - *Best* item is dequeued, queue manages itself to ensure operations are efficient

PriorityQueue *raison d'être*

- Algorithms Using PQ for efficiency
  - Shortest Path: Mapquest/Garmin to Internet Routing
    - How is this like word-ladder? How different?
  - Connecting all outlets in a house with minimal wiring
    - Minimal spanning tree in graph
  - Optimal A* search, game-playing, AI,
    - Can't explore entire search space, can estimate good move
- Data compression facilitated by priority queue
  - Alltime best assignment in a Compsci 100 course?
    - Subject to debate, of course
  - From A-Z, soup-to-nuts, bits to abstractions

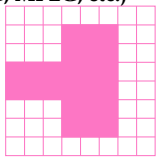
PQ Application: Data Compression

- 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?)
  - Who invented Napster, how old, when?
- 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
  - Will we ever need to stop worrying about storage?

More on Compression

- Different compression techniques
  - .mp3 files and .zip files?
  - .gif and .jpg?
  - Lossless and lossy
- Impossible to compress/lossless everything: 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 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 allow `getmin/peek` as well as delete
    - Analogous to top/pop, peek/dequeue in stacks, queues
- Think about implementing the ADT, choices?
  - Add compared to min/remove
  - Balanced search tree is ok, but can we do better?

Priority Queue sorting

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

```
String[] array = {...}; // array filled with data
PriorityQueue<String> pq = new PriorityQueue<String>();
for(String s : array) pq.add(s);
for(int k=0; k < array.length; k++){
   array[k] = pq.remove();
}
```

- Bottlenecks, operations in code above
  - Add words one-at-a-time to PQ v. all-at-once
  - What if PQ is an array, add or remove fast/slow?
  - We'd like PQ to have tree characteristics, why?

Priority Queue top-M sorting

- What if we have *lots and lots and lots* of data
  - code below sorts top-M elements, complexity?

```
Scanner s = … // initialize;
PriorityQueue<String> pq =
       new PriorityQueue<String>();
while (s.hasNext()) {
    pq.add(s.next());
    if (pq.size() > M) pq.remove();
}
```

- What's advantageous about this code?
  - Store everything and sort everything?
  - Store everything, sort first M?
  - What is complexity of sort: O(n log n)

Priority Queue implementations

- Priority queues: average and worst case

	Insert average	Getmin (delete)	Insert worst	Getmin (delete)
Unsorted list	O(1)	O(n)	O(1)	O(n)
Sorted list	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(n) build heap from n elements*

PriorityQueue.java (Java 5+)

- What about objects inserted into pq?
  - Comparable, e.g., essentially sortable
  - How can we change what *minimal* means?
  - Implementation uses *heap*, tree stored in an array
- 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?

Big-Oh and a tighter look at inserts

- `log(1) + log(2) + log(3) + … + log(n)`
  - Property of logs, `log(a) + log(b) = log(a*b)`
  - `log(1*2*3*…*n) = log(n!)`
- We can show using Sterling's formula:

$$n! \approx \sqrt{2n\pi} n^n e^{-n}$$

- `log(n!) = c1*log(n) + nlog(n) – c2*n`
- We can get O(n log n) easily, this goes tight, lower, Ω(n log n) as well

Priority Queue implementation

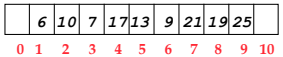
- Heap data structure is fast and reasonably simple
  - Why not use inheritance hierarchy as was used with Map?
  - Trade-offs when using HashMap and TreeMap:
    - Time, space, ordering properties, TreeMap support?
- Changing comparison when calculating priority?
  - Create object to replace, or in 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 <, ==, >

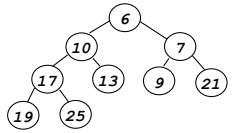
Creating Heaps

- Heap: array-based implementation of binary tree used for implementing priority queues:
  - add/insert, peek/getmin, remove/deletemin, O(???)
- Array minimizes storage (no explicit pointers), faster too, contiguous (cache) and indexing
- Heap has *shape* property and *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

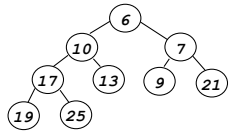
- store "node values" in array beginning at index 1
- for node with index k
  - left child: index `2*k`
  - right child: index `2*k+1`
- why is this conducive for maintaining heap shape?
- what about heap property?
- is the heap a search tree?
- where is minimal node?
- where are nodes added? deleted?

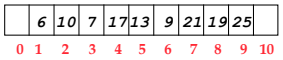




Thinking about heaps

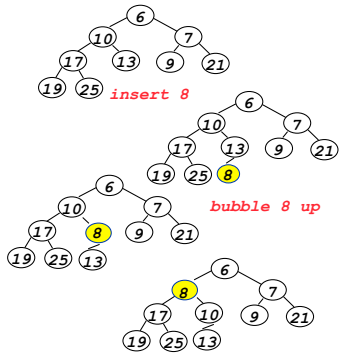
- Where is minimal element?
  - Root, why?
- Where is maximal element?
  - Leaves, why?
- How many leaves are there in an N-node heap (big-Oh)?
  - O(n), but exact?
- What is complexity of find max in a minheap? Why?
  - O(n), but ½ N?
- Where is second smallest element? Why?
  - Near root?



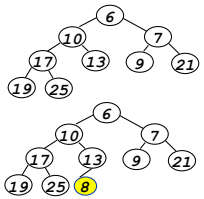


Adding values to heap

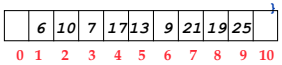
- to maintain heap shape, must add new value in left-to-right order of last level
  - could violate *heap property*
  - move value "up" if too small
- change places with parent if heap property violated
  - stop when parent is smaller
  - stop when root is reached
- pull parent down, swapping isn't necessary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



Adding values, details (pseudocode)



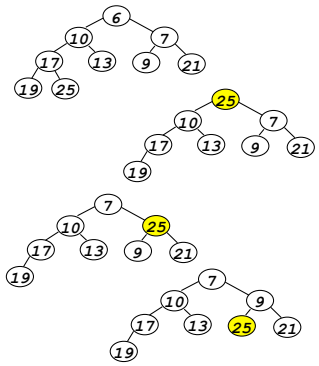
```
void add(Object elt)
{
  // add elt to heap in myList
  myList.add(elt);
  int loc = myList.size()-1;

  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);
}
```



array myList

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."
- http://www.youtube.com/watch?v=1yPxd5jqz_Q