**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, ...
**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?

```java
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?

```java
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

<table>
<thead>
<tr>
<th></th>
<th>Insert average</th>
<th>Getmin (delete)</th>
<th>Insert worst</th>
<th>Getmin (delete)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsorted list</td>
<td>0(1)</td>
<td>0(n)</td>
<td>0(1)</td>
<td>0(n)</td>
</tr>
<tr>
<td>Sorted list</td>
<td>0(n)</td>
<td>0(1)</td>
<td>0(n)</td>
<td>0(1)</td>
</tr>
<tr>
<td>Search tree</td>
<td>log n</td>
<td>log n</td>
<td>log n</td>
<td>log n</td>
</tr>
<tr>
<td>Balanced tree</td>
<td>log n</td>
<td>log n</td>
<td>log n</td>
<td>log n</td>
</tr>
<tr>
<td>Heap</td>
<td>0(1)</td>
<td>log n</td>
<td>0(n)</td>
<td>log n</td>
</tr>
</tbody>
</table>

- 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

- \[ \log(1) + \log(2) + \log(3) + \ldots + \log(n) \]
  - Property of logs, \( \log(a) + \log(b) = \log(a \cdot b) \)
  - \( \log(1 \cdot 2 \cdot 3 \ldots n) = \log(n!) \)

- We can show using Sterling’s formula:
  \[ n! \approx \sqrt{2\pi n} n^n e^{-n} \]

- \( \log(n!) = c_1 \cdot \log(n) + n \log(n) - c_2 \cdot n \)
- We can get \( O(n \log n) \) easily, this goes tight, lower, \( \Omega(n \log n) \) 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 \( \frac{1}{2} N \)?
- 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)
```java
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;
    }
    // what’s true here?
    mylist.set(loc,elt);
}
```

Array-based heap diagram:
it shows a binary tree with nodes labeled 6, 10, 7, etc., and children described by indices 2\*k and 2\*k + 1.

Thinking about heaps diagram:
it illustrates the location of minimal and maximal elements in a heap, with a binary tree showing leaves as maximal.

Adding values to heap diagram:
it depicts the process of inserting a new value into a heap, showing the movement up the tree if necessary.

Adding values, details (pseudocode) diagram:
it visualizes the pseudocode for the `add` method, with arrows indicating the movement of elements in the heap.
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=1yPxkSjajz Q]