CS 2230
CS II: Data structures

Meeting 31: Priority queue
Brandon Myers
University of Iowa
Today’s Learning objectives

• Describe how a PriorityQueue would be used in a specific real application
• Interpret code that uses PriorityQueue
High level view of a web search engine

Preparation before you searched this morning

1. A ”web crawler” finds new or modified pages and puts them into a Map<String,List<String>> where
   • keys are words found in the page
   • values are the list of URLs where that word is found
   (dog, [www.petco.com, en.wikipedia.org/wiki/Dog])
   (iowa, [uiowa.edu, en.wikipedia.org/wiki/iowa, azdailysun.com/.../iowa/article...])
High level view of a web search engine

Preparation before you searched this morning

1. A “web crawler” finds new or modified pages and puts them into a Map<String, List<String>> where
   • keys are words found in the page
   • values are the list of URLs where that word is found
   (dog, [www.petco.com, en.wikipedia.org/wiki/Dog])
   (Iowa, [uiowa.edu, en.wikipedia.org/wiki/Iowa, azdailysun.com/.../iowa/article...])

2. A base ranking of each page is calculated based on features like
   • how relevant the website is for that search term
   • the quality of the website
   • ... List of ranked pages could instead be a “priority queue” that sorts pages by rank
   (leash, [1 www.petco.com, 1 amazon.com, 5 https://en.wikipedia.org/wiki/Leash, ...])
   (Iowa, [1 uiowa.edu, 1 en.wikipedia.org/wiki/Iowa, ..., 944 azdailysun.com/.../iowa/article, ...])
When you search

lookup key “iowa”

(Iowa, [1 en.wikipedia.org/wiki/Iowa, 1 iowa.gov, 1 uiowa.edu, ..., 944 azdailysun.com/.../iowa/article])

return just the top 10 ranked results at a time

note: In real search engines, the combination of words is vitally important to ranking. For example, wikipedia’s rank for “iowa dogs” will be much lower than its rankings for the individual words “iowa” and “dog"
Describe how a PriorityQueue would be used in a specific real application

Situations where the order an element enters the queue doesn’t determine the order it leaves, due to priorities

<table>
<thead>
<tr>
<th>scenario</th>
<th>element</th>
<th>enter queue when</th>
<th>priority determined by</th>
</tr>
</thead>
<tbody>
<tr>
<td>web crawler in a search engine</td>
<td>a web page</td>
<td>web crawler finds the new or changed page</td>
<td>relevance to keyword, quality of site, ...</td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Give an example scenario (limit your submitted answer to this column)

Fill in the other 3 columns for your scenario

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Priority queue applications

Situations where the order an element enters the queue doesn’t determine the order it leaves, due to priorities

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<td>air traffic control</td>
<td>airplane</td>
<td>the flying airplane gets close to the airport</td>
<td>late flights go first, planes low on fuel go first, ...</td>
</tr>
<tr>
<td>UI course waitlist</td>
<td>student</td>
<td>register for a class</td>
<td>class level, whether you are in the major, ...</td>
</tr>
</tbody>
</table>
An ADT for priority queues

```java
interface PriorityQueue<P extends Comparable<P>, V> {
    // adds value with the given priority
    void insert (P priority, V value);

    // returns and removes the value with minimum priority
    V deleteMin();

    // returns the value with the minimum key
    V min();

    int size(); // return # of entries
    boolean isEmpty(); // return true if empty
}
```
Interpret code that uses PriorityQueue

```java
PriorityQueue<Integer,String> q = // create it;
q.insert(3, "Cat")
q.insert(5, "Doggy")
q.insert(2, "Jo")
print(q.min() + " ")
println(q.deleteMin() + " ")
q.insert(2, "Oh")
q.deleteMin()
println(q.deleteMin() + " ")
```

What does the program print?

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Today’s Learning objectives

• Describe how a PriorityQueue would be used in a specific real application
• Interpret code that uses PriorityQueue
CS 2230
CS II: Data structures
Meeting 32: Priority queue implementations, binary heaps
Brandon Myers
University of Iowa
Today’s Learning objectives

• Analyze running time of methods for various PriorityQueue implementations
• Identify whether a binary tree is a heap
• Identify the array representation of a heap
• Execute heap algorithms for insert and deleteMin
• Write an algorithm that uses a PriorityQueue
Analyze running time of methods for various PriorityQueue implementations

Use an array that stores elements in arbitrary order. What is the insert time? What is the deleteMin time?

10 14 4 15 7 21

insert, deleteMin

a) O(1) amortized, O(logn)
b) O(logn), O(logn)
c) O(n), O(1)
d) O(n), O(n)
e) O(1) amortized, O(n)

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Analyze running time of methods for various PriorityQueue implementations

Use an array that stores elements in sorted order in a linked list. What is the insert time? What is the deleteMin time?

insert, deleteMin

a) O(1), O(log n)
b) O(n), O(log n)
c) O(n), O(1)
d) O(log n), O(1)
e) O(n), O(n)

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binary heap

another representation for a priority queue is a binary tree filled top to bottom that has the

heap property

• for a min heap: Key at a node ≥ Key at its parent
• for a max heap: Key at a node ≤ Key at its parent

example of a binary min heap
Identify whether a binary tree is a heap

Which of the following is a valid binary max heap?

a)
```
  17
 /  \
15   10
 / \
6   10
```

b)
```
  17
 / \
15   10
 / \
6   10
```

c)
```
  16
 /  \
13   20
   /  \
 2   14   17
```

d)
```
  1
 /  \
2   3
  /  \
17   19
 /  \
25   38
   /  \
100
```

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Array representation of a binary heap

for parent at index $k$, child nodes are stored at
$left=2k$
$right=2k+1$
$parent=[k/2]$

we are leaving index 0 empty...why?
Identify the array representation of a heap

What is the array representation of this min heap?

give your answer as a comma separated list
Project notes
Inserting into a heap

```
1
/   \
4    2
/     /
9    13
/     /
7      5
```

insert 3

```
1
/   \
4    2
/     /
9    13
/     /
7      5
```

put it in the next available spot

```
1
/   \
4    2
/     /
9    13
/     /
7      5
```

```
1
/   \
4    2
/     /
9  7
/     /
22  12 8
```

```
1
/   \
4    2
/     /
9  7
/     /
22  12 8
```

```
1
/   \
4    2
/     /
9  7
/     /
22  12 8
```

```
1
/   \
4    2
/     /
9  7
/     /
22  12 3
```
bubble up the inserted node until its parent is smaller than it
Execute heap algorithms for insert and deleteMin

draw the heap after G is inserted

what level is G at?
a) 1 (where A is now)
b) 2
c) 3
d) 4 (where M is now)
Deleting from a binary heap

Before:
- 1
  - 4
    - 9
      - 22
    - 7
    - 13
    - 5
  - 2

After:
- 9
  - 4
    - 22
  - 12
  - 8

Key 1 returned
8 moved to root
Deleting from a binary heap

1. Left heap: 1, 4, 2, 9, 7, 13, 5, 22, 12, 8
2. Right heap: 4, 2, 8

**Step 1:**
- **Operation:** deleteMin
- **Result:** Key 1 returned

**Step 2:**
- 8 moved to root

**Step 3:**
- **Operation:** replace root
- **Result:** 2, 4, 5, 9, 7, 13, 8

**Step 4:**
- **Operation:** replace root
- **Result:** 2, 4, 8, 9, 7, 13, 5
Execute heap algorithms for insert and deleteMin

draw the heap after deleteMin()

what level is M at?
a) 1 (where A is now)
b) 2
c) 3
d) 4 (where M is now)

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Analyze running time of methods for various PriorityQueue implementations

Using a binary min heap for our Priority queue, what is the insert and deleteMin time?

insert, deleteMin

a) O(1), O(logn)
b) O(logn), O(1)
c) O(n), O(1)
d) O(logn), O(logn)
e) O(n), O(n)

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Write an algorithm that uses a PriorityQueue

Next topic is sorting. How would you sort an array of numbers (small to large) using PriorityQueue?

```java
void sort(int[] number) {
    interface PriorityQueue<P extends Comparable<P>, V> {
        void insert (P priority, V value);
        V deleteMin();
        V min();
        int size();
        boolean isEmpty();
    }
}
```

*Assume there is an class called HeapPriorityQueue that implements PriorityQueue*
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resources

• animations of heaps

http://www.cs.usfca.edu/~galles/visualization/Heap.html
acknowledgements

heap insert/deleteMin diagrams
http://homepage.divms.uiowa.edu/~ghosh/2116.8.pdf