Priority Queues: Binary Min Heaps

CSE 373
Data Structures and Algorithms

Today’s Outline

• Announcements
  – Assignment #2 due Fri, Oct 12 at the BEGINNING of lecture
  – Midterm #1, Fri, Oct 19.
  – Assignment #3 coming soon, due Thurs, Oct 25.

• Today’s Topics:
  – Dictionary
    • Balanced Binary Search Trees - (AVL Trees)
  – Priority Queues
    • Binary Min Heap

Priority Queue ADT

1. PQueue data: collection of data with priority

2. PQueue operations
   – insert
   – deleteMin
     (also: create, destroy, is_empty)

3. PQueue property: for two elements in the queue, x and y, if x has a lower priority value than y, x will be deleted before y
Applications of the Priority Q

- Select print jobs in order of decreasing length
- Forward packets on network routers in order of urgency
- Select most frequent symbols for compression
- Sort numbers, picking minimum first

- Anything greedy

Implementations of Priority Queue ADT

<table>
<thead>
<tr>
<th></th>
<th>insert</th>
<th>deleteMin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsorted list (Array)</td>
<td></td>
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<tr>
<td>Unsorted list (Linked-List)</td>
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<tr>
<td>Sorted list (Array)</td>
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<tr>
<td>Sorted list (Linked-List)</td>
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<tr>
<td>Binary Search Tree (BST)</td>
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</tbody>
</table>

Representing Complete Binary Trees in an Array

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>

From node i:
left child: node 2i + 1
right child: node 2i + 2
parent: node i

implicit (array) implementation:
Why better than tree with pointers?

Heap **Order** Property

**Heap order property:** For every non-root node X, the value in the parent of X is less than (or equal to) the value in X.

Heap Operations

- **findMin:**
- **insert(val):** percolate up.
- **deleteMin:** percolate down.
Heap – Insert(val)

Basic Idea:
1. Put val at “next” leaf position
2. Repeatedly exchange node with its parent if needed

Insert pseudo Code (optimized)

```java
void insert(Object o) {
    assert(!isFull());
    size++;
    newPos = percolateUp(size, o);
    Heap[newPos] = o;
}

int percolateUp(int hole, Object val) {
    while (hole > 1 && val < Heap[hole/2]) {
        Heap[hole] = Heap[hole/2];
        hole /= 2;
    }
    return hole;
}
```

runtime:

(Java code in book)
Heap – DeleteMin

Basic Idea:
1. Remove root (that is always the min!)
2. Put “last” leaf node at root
3. Find smallest child of node
4. Swap node with its smallest child if needed.
5. Repeat steps 3 & 4 until no swaps needed.

DeleteMin pseudo Code (Optimized)

```java
int percolateDown(int hole, Object val) {
    while (2*hole <= size) {
        left = 2*hole;
        right = left + 1;
        if (right <= size && Heap[right] < Heap[left]) {
            target = right;
        } else {
            target = left;
        }
        if (Heap[target] < val) {
            Heap[hole] = Heap[target];
            hole = target;
        } else {
            break;
        }
    }
    return hole;
}
```

DeleteMin: percolate down
Other Priority Queue Operations

- **decreaseKey**
  - given a pointer to an object in the queue, reduce its priority value
  Solution: change priority and ____________________________

- **increaseKey**
  - given a pointer to an object in the queue, increase its priority value
  Solution: change priority and ____________________________

Why do we need a pointer? Why not simply data value?

Other Heap Operations

decreaseKey(objPtr, amount): raise the priority of an object, percolate up
decreaseKey(objPtr, amount): lower the priority of an object, percolate down
remove(objPtr): remove an object, move to top, then delete.
  1) decreaseKey(objPtr, ∞)
  2) deleteMin()

Worst case Running time for all of these:
  FindMax?
  ExpandHeap – when heap fills, copy into new space.
Binary Min Heaps (summary)

- **insert**: percolate up. $\Theta(\log N)$ time.
- **deleteMin**: percolate down. $\Theta(\log N)$ time.
- **Build Heap?**

BuildHeap: Floyd’s Method

Add elements arbitrarily to form a complete tree. Pretend it’s a heap and fix the heap-order property!

Buildheap pseudocode

```java
private void buildHeap() {
    for (int i = currentSize/2; i > 0; i--)
        percolateDown(i);
}
```

runtime:
Finally…

BuildHeap: Floyd’s Method

runtime: