

## CS61B Lecture #23

### Today:

- Priority queues (*Data Structures* §6.4, §6.5)
- Range queries (§6.2)
- Java utilities: SortedSet, Map, etc.

**Next topic:** Hashing (*Data Structures* Chapter 7).

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## Priority Queues, Heaps

- Priority queue: defined by operations "add," "find largest," "remove largest."
- Examples: scheduling long streams of actions to occur at various future times.
- Also useful for sorting (keep removing largest).
- Common implementation is the [heap](#), a kind of tree.
- (Confusingly, this same term is used to describe the pool of storage that the **new** operator uses. Sorry about that.)

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## Heaps

- A [max-heap](#) is a binary tree that enforces the [Heap Property](#): Labels of [both](#) children of each node are less than node's label.
- So node at top has largest label.
- Looser than binary search property, which allows us to keep tree "bushy".
- That is, it's always valid to put the smallest nodes anywhere at the bottom of the tree.
- Thus, heaps can be made [nearly complete](#): all but possibly the last row have as many keys as possible.
- As a result, insertion of new value and deletion of largest value always take time proportional to  $\lg N$  in worst case.
- A [min-heap](#) is basically the same, but with the minimum value at the root and children having larger values than their parents.

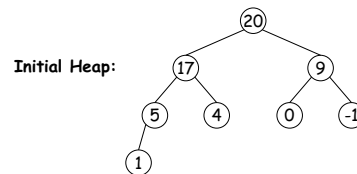
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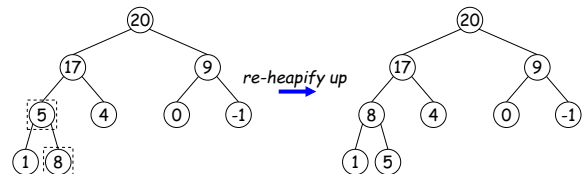
## Example: Inserting into a simple heap

**Data:**

1 17 4 5 9 0 -1 20



**Add 8:** Dashed boxes show where heap property violated

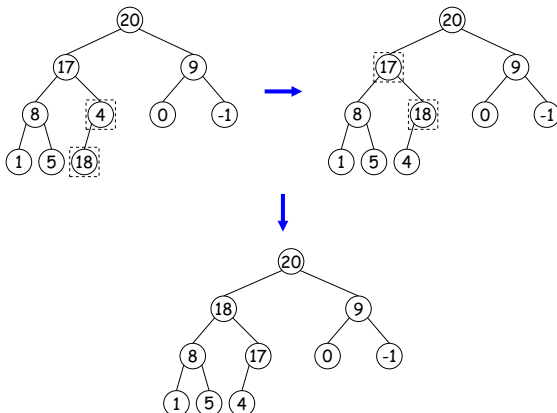


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## Heap insertion continued

**Now insert 18:**

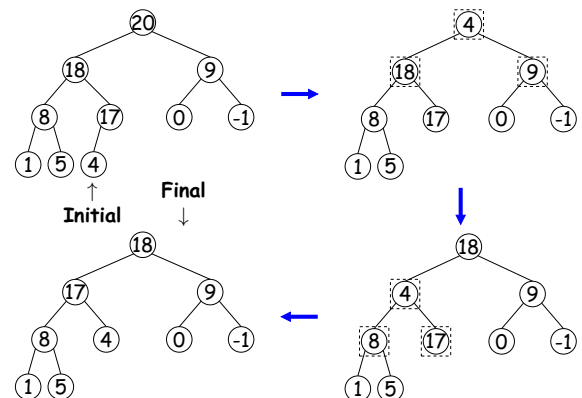


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## Removing Largest from Heap

**To remove largest:** Move bottommost, rightmost node to top, then re-heapify down as needed (swap offending node with larger child) to re-establish heap property.

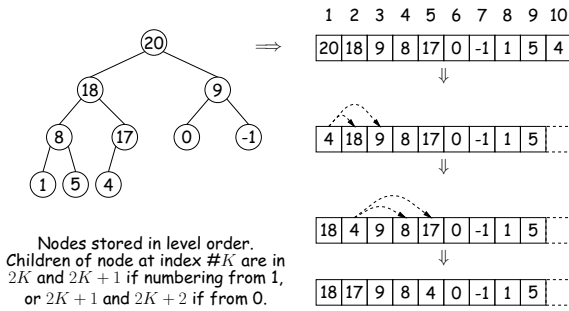


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## Heaps in Arrays

- Since heaps are nearly complete (missing items only at bottom level), can use arrays for compact representation.
- Example of removal from last slide (dashed arrows show children):



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## Ranges

- So far, have looked for specific items
- But for BSTs, need an ordering anyway, and can also support looking for *ranges of values*.
- Example: perform some action on all values in a BST that are within some range (in natural order):

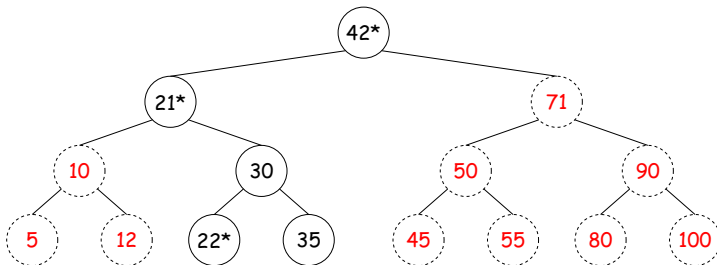
```
/** Apply WHATTODO to all labels in T that are >= L and < U,
 * in ascending natural order. */
static void visitRange(BST<String> T, String L, String U,
    Consumer<BST<String>> whatToDo) {
    if (T != null) {
        int comLeft = L.compareTo(T.label ()),
            comRight = U.compareTo(T.label ());
        if (comLeft < 0) /* L < label */
            visitRange (T.left(), L, U, whatToDo);
        if (comLeft <= 0 && comRight > 0) /* L <= label < U */
            whatToDo.accept(T);
        if (comRight > 0) /* label < U */
            visitRange (T.right (), L, U, whatToDo);
    }
}
```

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## Time for Range Queries

- Time for range query  $\in O(h + M)$ , where  $h$  is height of tree, and  $M$  is number of data items that turn out to be in the range.
- Consider searching the tree below for all values  $25 \leq x < 40$ .
- Dashed** nodes are never looked at. Starred nodes are looked at but not output. The  $h$  comes from the starred nodes; the  $M$  comes from unstarred non-dashed nodes.



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## Ordered Sets and Range Queries in Java

- Class SortedSet supports range queries with *views* of set:
  - $S.headSet(U)$ : subset of  $S$  that is  $< U$ .
  - $S.tailSet(L)$ : subset that is  $\geq L$ .
  - $S.subSet(L, U)$ : subset that is  $\geq L, < U$ .
- Changes to views modify  $S$ .
- Attempts to, e.g., add to a headSet beyond  $U$  are disallowed.
- Can iterate through a view to process a range:

```
SortedSet<String> fauna = new TreeSet<String>()
    (Arrays.asList ("axolotl", "elk", "dog", "hartebeest", "duck"));
for (String item : fauna.subSet ("bison", "gnu"))
    System.out.printf ("%s, ", item);
```

would print "dog, duck, elk,"

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## TreeSet

- Java library type TreeSet< $T$ > requires either that  $T$  be Comparable, or that you provide a Comparator, as in:

```
SortedSet<String> rev_fauna = new TreeSet<String>(Collections.reverseOrder());
```

- Comparator is a type of function object:

```
interface Comparator<T> {
    /** Return <0 if LEFT<RIGHT, >0 if LEFT>RIGHT, else 0. */
    int compare(T left, T right);
}
```

(We'll deal with what Comparator< $T$ > extends Comparable< $T$ > is all about later.)

- For example, the reverseOrder comparator is defined like this:

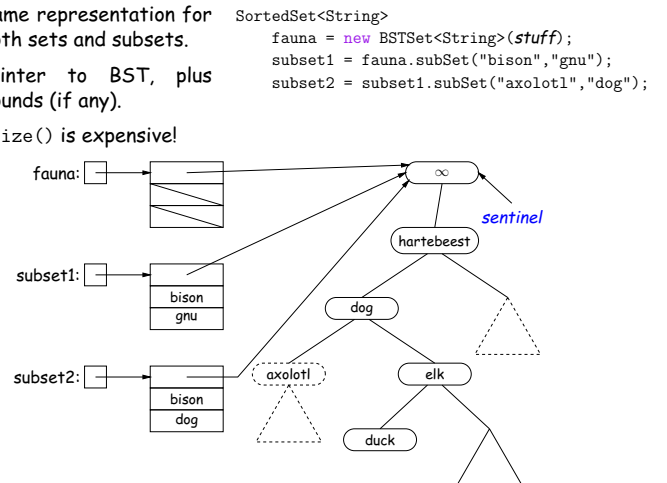
```
/** A Comparator that gives the reverse of natural order. */
static <T extends Comparable<T>> Comparator<T> reverseOrder() {
    // Java figures out this lambda expression is a Comparator<T>. corrected 3/24
    return (x, y) -> y.compareTo(x);
}
```

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## Example of Representation: BSTSet

- Same representation for both sets and subsets.
- Pointer to BST, plus bounds (if any).
- `.size()` is expensive!



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