CS61B Lecture #25

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).

Priority Queues, Heaps

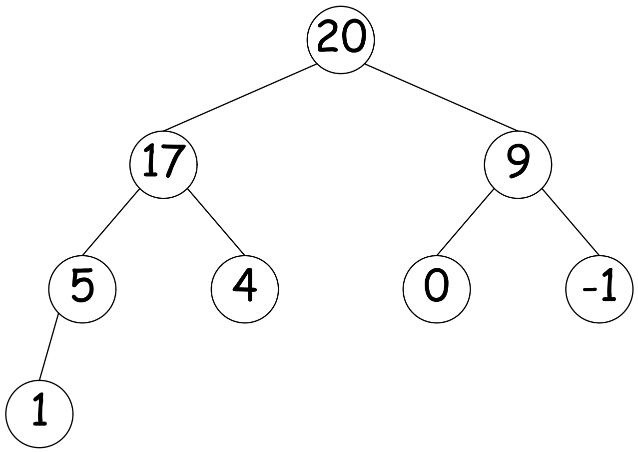
- Priority queue: defined by operations "add," "find largest," "remove largest."
- Examples: scheduling long streams of actions to occur at various future times.
- Also useful for sorting (keep removing largest).
- Heap is common implementation.
- Enforces *heap property:* all labels in *both* children of node are less (or greater) than node's label.
- So node at top has largest (or smallest) label.
- Are free to add smaller value to less bushy subtree, thus maintaining bushiness (keeping tree balanced).
- Insertion and deletion always proportional to $\lg N$ in worst case.

Example: Inserting into a simple heap

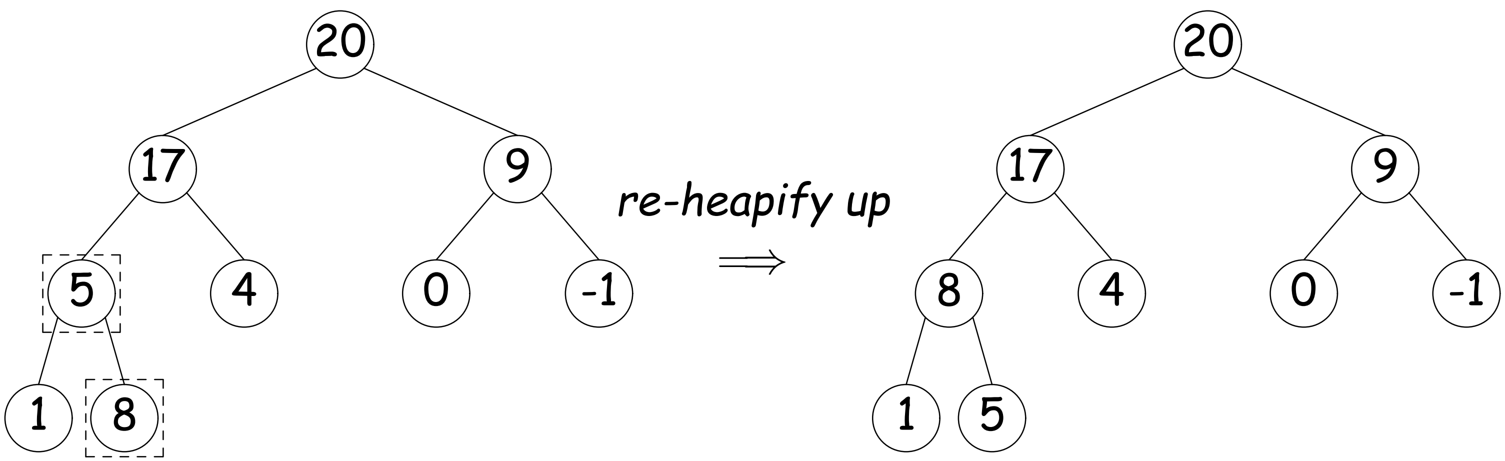
Data:

1 17 4 5 9 0 −1 20

Initial Heap:

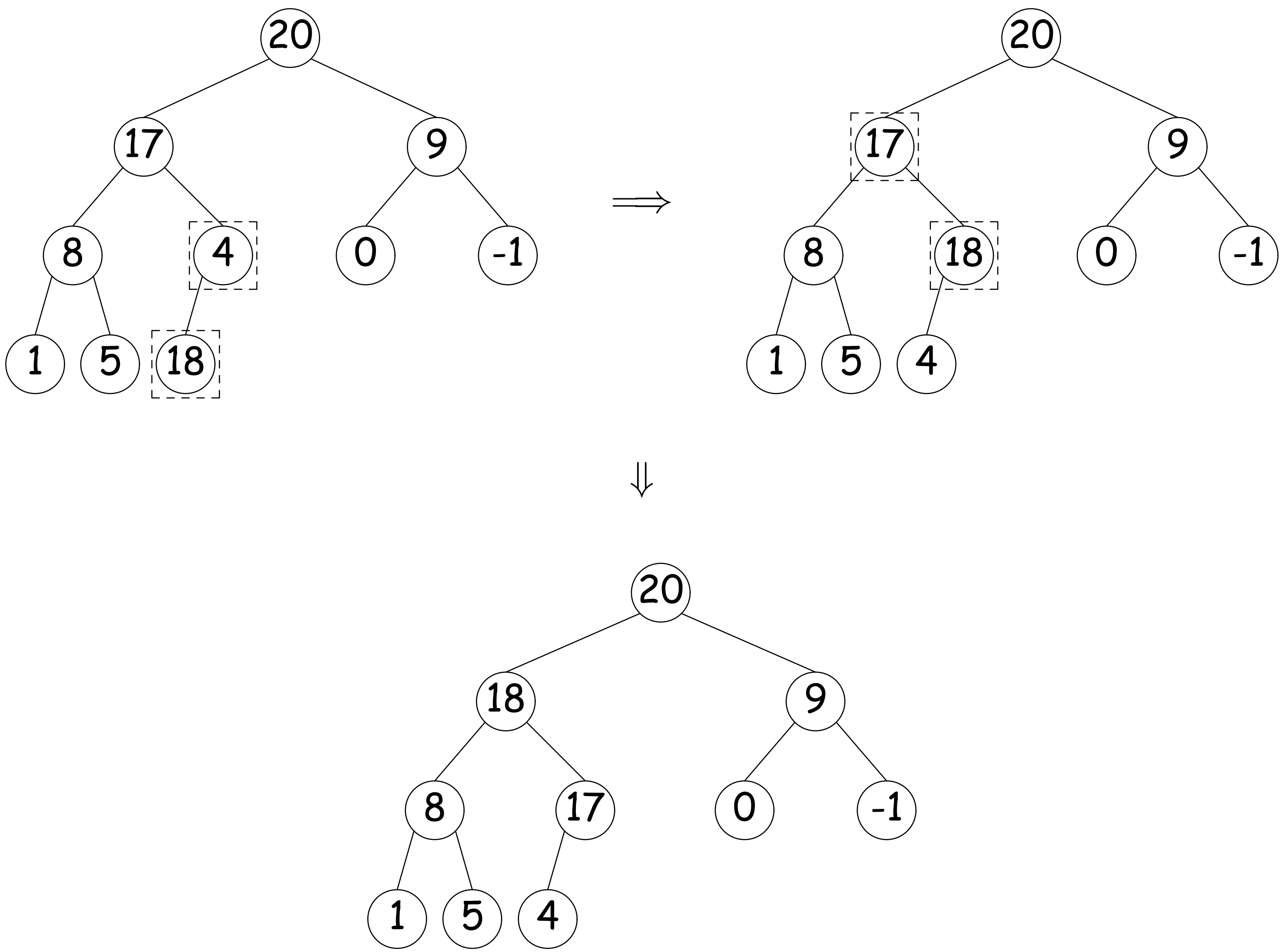


Add 8: Dashed boxes show where heap property violated



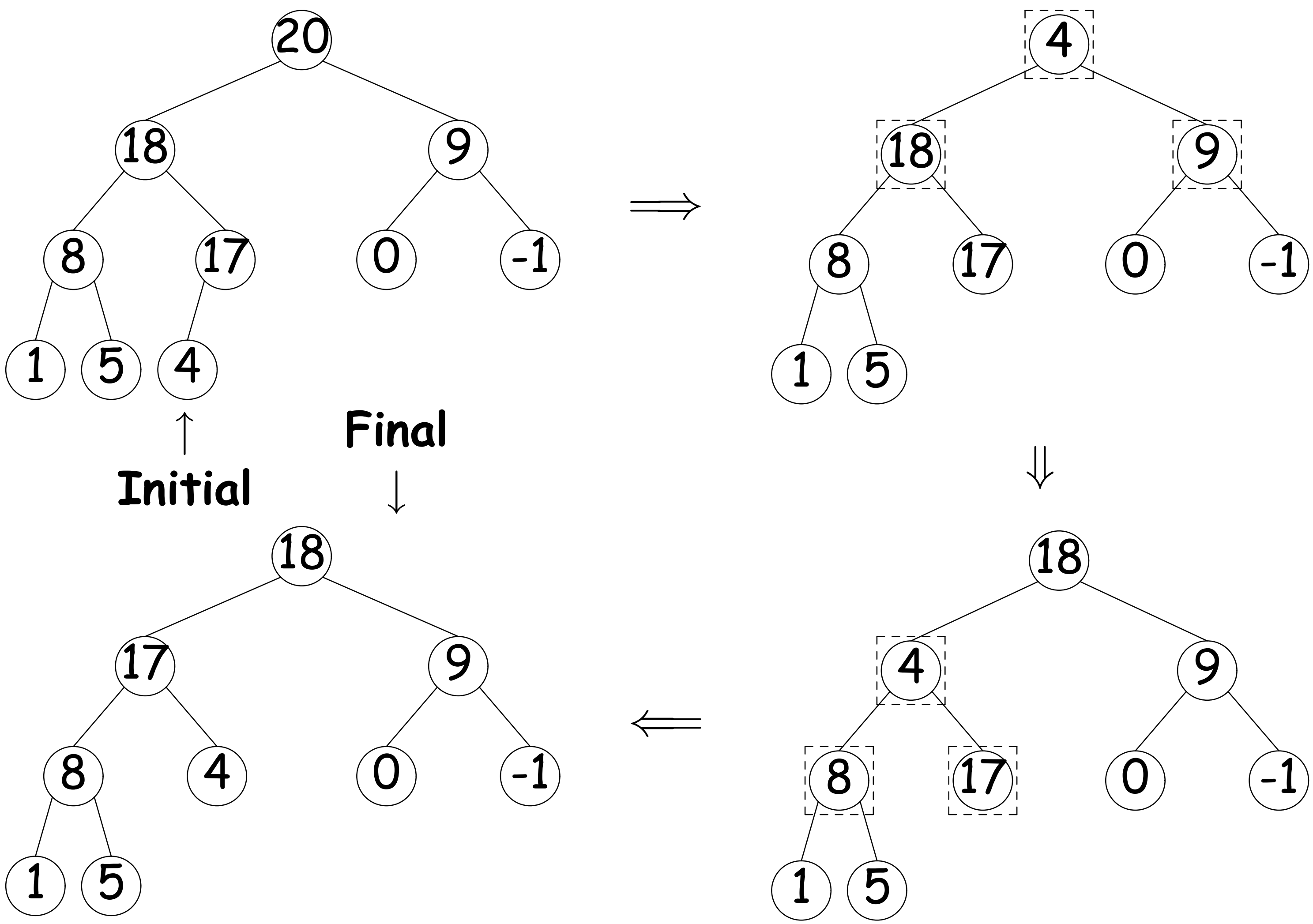
Heap insertion continued

Now insert 18:



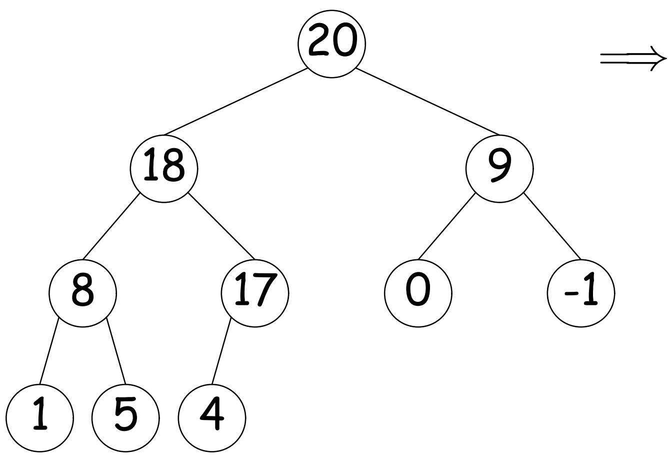
Removing Largest from Heap

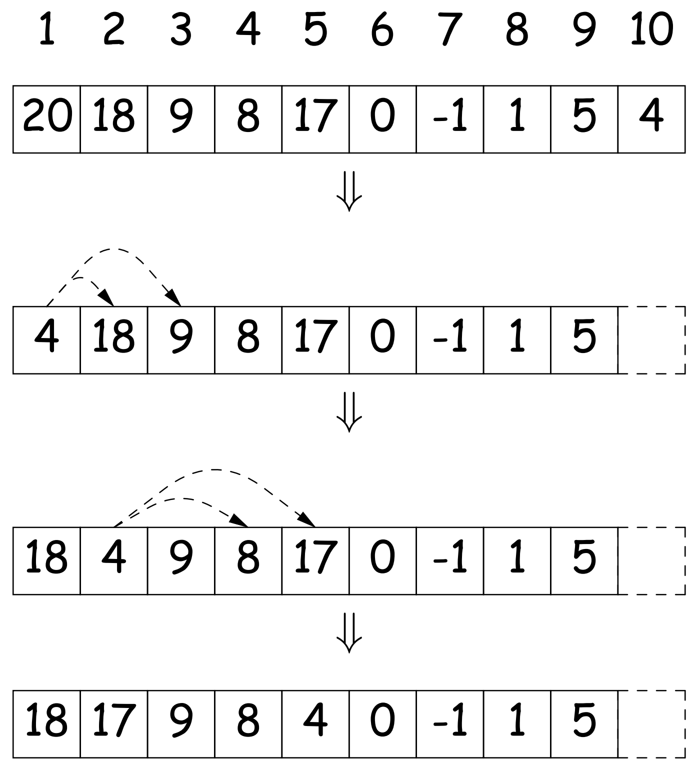
To remove largest: Move bottommost, rightmost node to top, then re-heapify down as needed (swap offending node with larger child) to re-establish heap property.



Heaps in Arrays

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





Nodes stored in level order.
Children of node at index $\#K$
are in $2K$ and $2K+1$

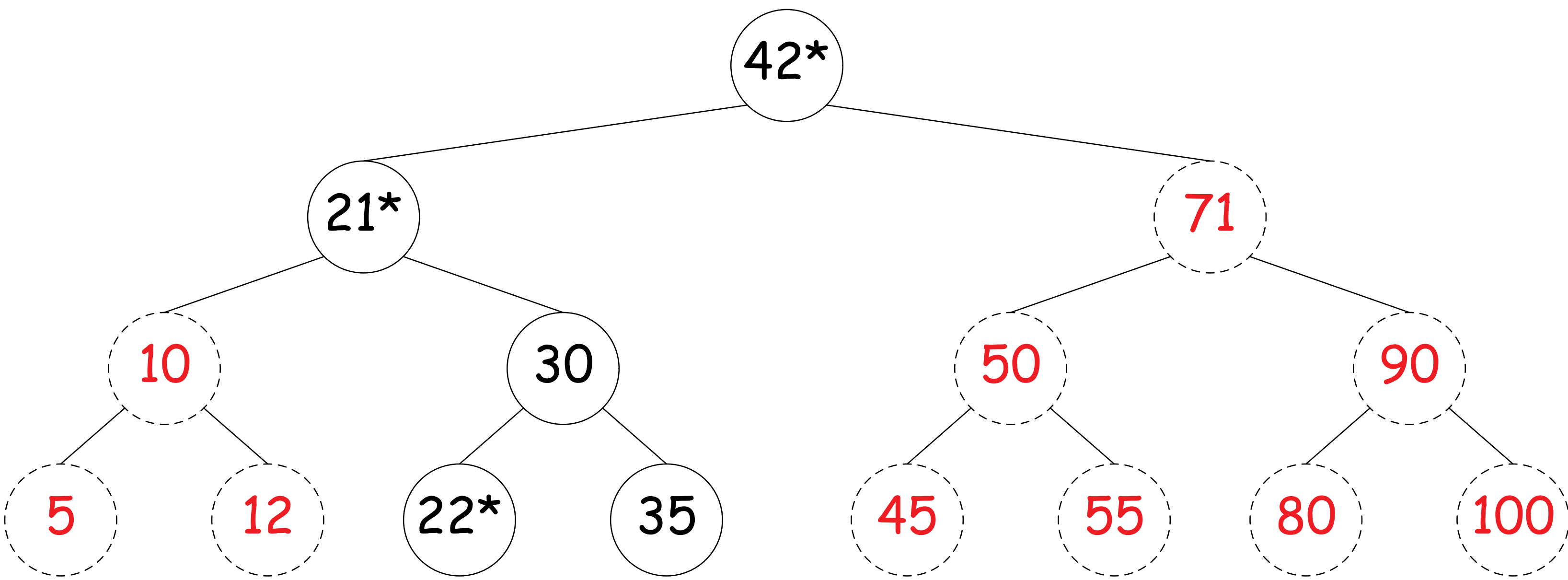
Ranges

- 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 T, Comparable<Key> L, Comparable<Key> U,
                        Action whatToDo)
  if (T != null) {
    int compLeft = L.compareTo (T.label ()),
        compRight = U.compareTo (T.label ());
    if (compLeft < 0)  /* L < label */
      visitRange (T.left (), L, U, whatToDo);
    if (compLeft <= 0 && compRight > 0) /* L <= label < U */
      whatToDo.action (T);
    if (compRight > 0)  /* label < U */
      visitRange (T.right (), L, U, whatToDo);
  }
}
```

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, x, such that $25 \leq x < 40$.
- In this example, the h comes from the starred nodes; the M comes from other non-dashed nodes. Dashed nodes are never looked at.



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

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

Example of Representation: BSTSet

- Use binary search tree to represent set. Can use same representation for both `BSTSet` and its subsets.
- Each set has pointer to BST, plus bounds (if any).
- In this representation, `size` is rather expensive!

```
SortedSet<String>
  fauna = new BSTSet<String> (collection of stuff);
  subset = fauna.subSet ("bison","gnu");
Iterator<String> i = subset.iterator ();
```