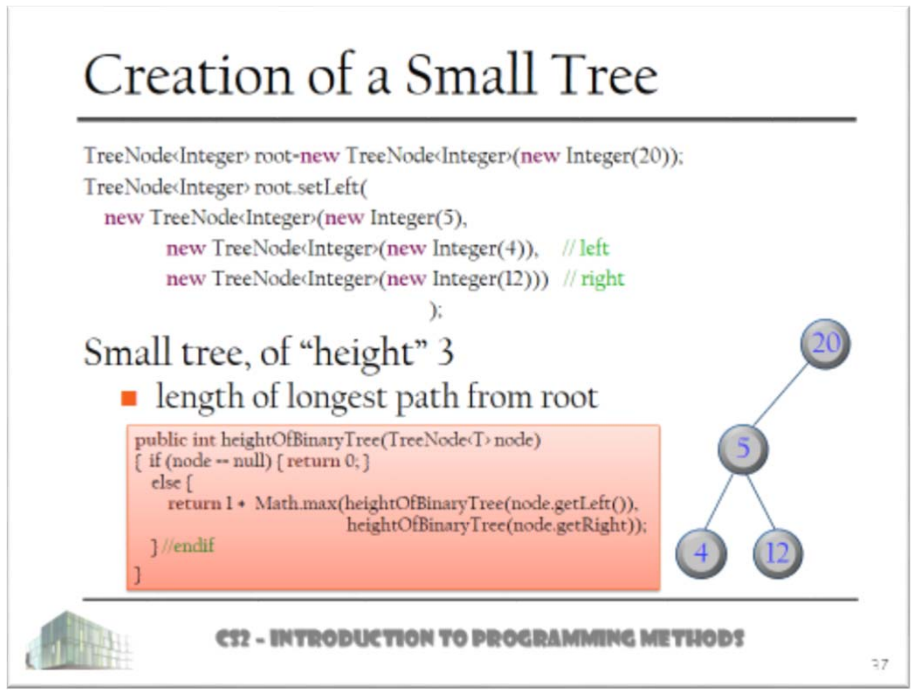
CS 2

Introduction to Programming Methods

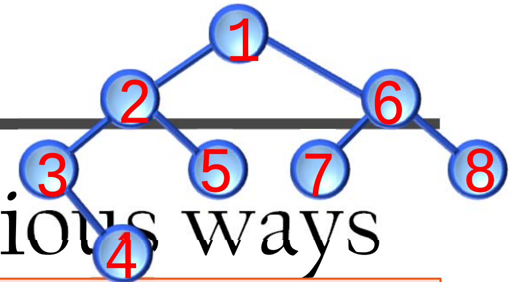
Last Time

Intro to data structures

- how to store your data in a convenient form
  - arrays, linked lists
  - started trees too



Traversal

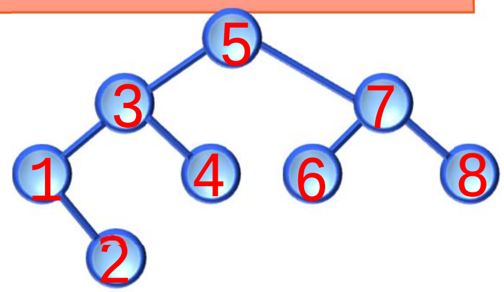


Can traverse a binary tree in various ways

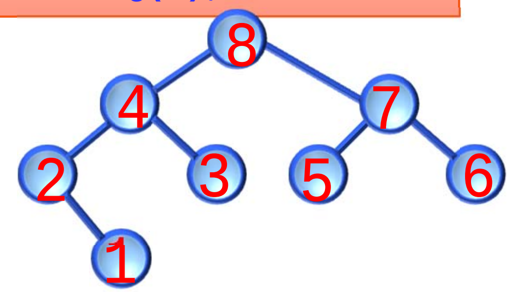
- In-order
- Pre-order
- Post-order
- others too…
  - e.g., per level

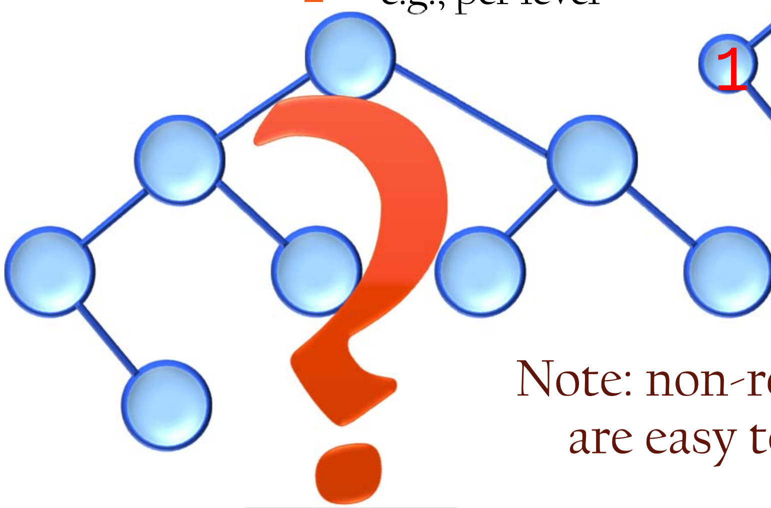
```
// InOrder traversal
inOrder(TreeNode<T> n) {
 if (n != null) {
   inOrder(n.getLeft());
   doSomething(n)
   inOrder(n.getRight());}}
```

```
// PreOrder traversal
PreOrder(TreeNode<T> n) {
 if (n != null) {
   doSomething(n)
   PreOrder(n.getLeft());
   PreOrder(n.getRight());}}
```




```
// PostOrder traversal
PostOrder(TreeNode<T> n) {
 if (n != null) {
   PostOrder(n.getLeft());
   PostOrder(n.getRight());
   doSomething(n);}}
```





Note: non-recursive (iterative) ways are easy too (using, e.g., a stack)

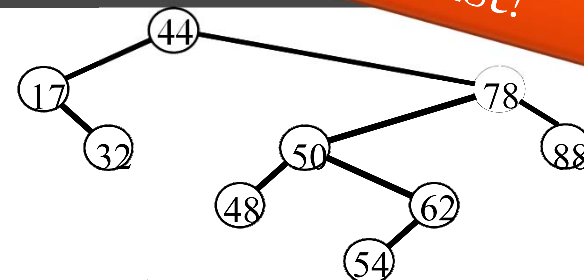
Balanced Binary Search Trees (AVL)

A particularly good type of tree if you want:

- to store n values (records) in O(n)
- to search, insert, delete in O(log n)
  - obviously, a simple linked list won't do
  - … but we discussed "binary search" earlier
    - data structure inspired by this algorithm
      - » **keep data ordered**
      - » **keep data in log n levels**
- note: will assume no two (or more) elements the same to avoid complication

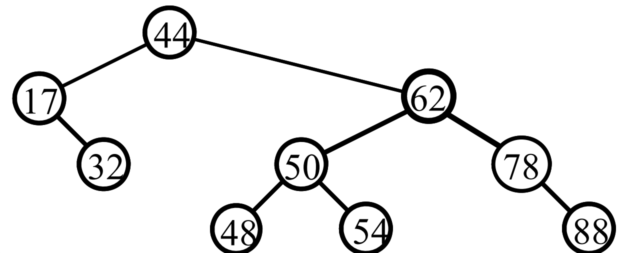
Two Definitions

in-order traversal? ordered list!



Binary search tree

- for any node *n* in the tree:
  - nodes in **left subtree** of *n* contain items **less than** the item of *n*
  - nodes in **right subtree** of *n* contain items **greater than** the item of *n*



Balanced tree

- for any node n:
  - height(left) = height(right) (± 1)

Balanced binary search tree

- you guessed it…

Search in Binary Search Tree

Start at the root, and visit subtrees

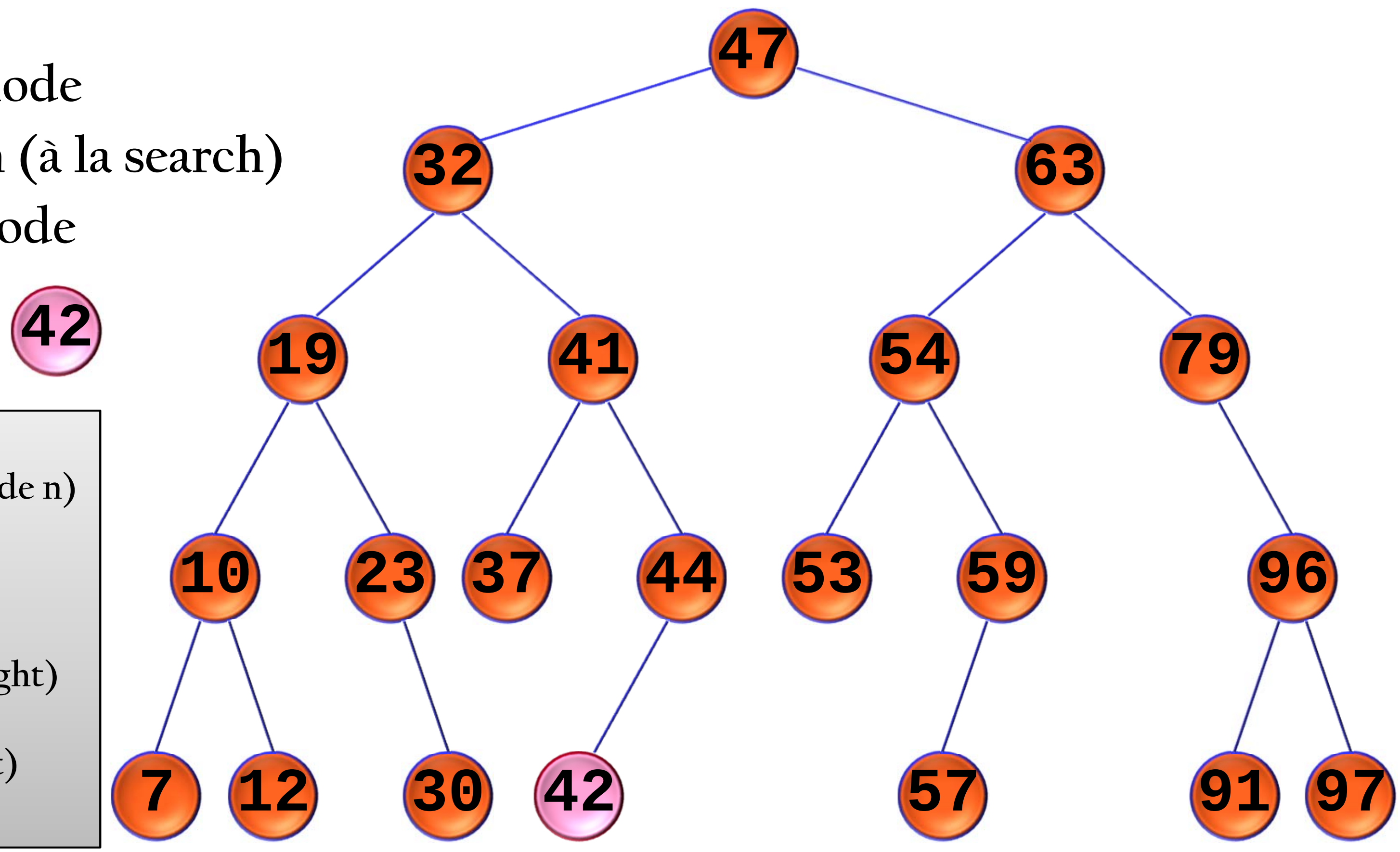
- cost?

```
TreeNode<T> findNode(TreeNode<T> n, T value)
  // returns a node containing the item containing “value”
  // or null if not found
  {
    if (n == null) { return null; }
    else {
      // if found, return n
      if (value == n.getItem()) { return n; }
      // otherwise search the left or right subtree
      else if (value < n.getItem())
           { return findNode(n.getLeft(),  value); }
      else { return findNode(n.getRight(), value); } // end if
    } // end if
  } // end findNode
```

Insertion in Binary Search Tree?

Insert 42?

- create new node
- find position (à la search)
- insert new node



Pseudocode

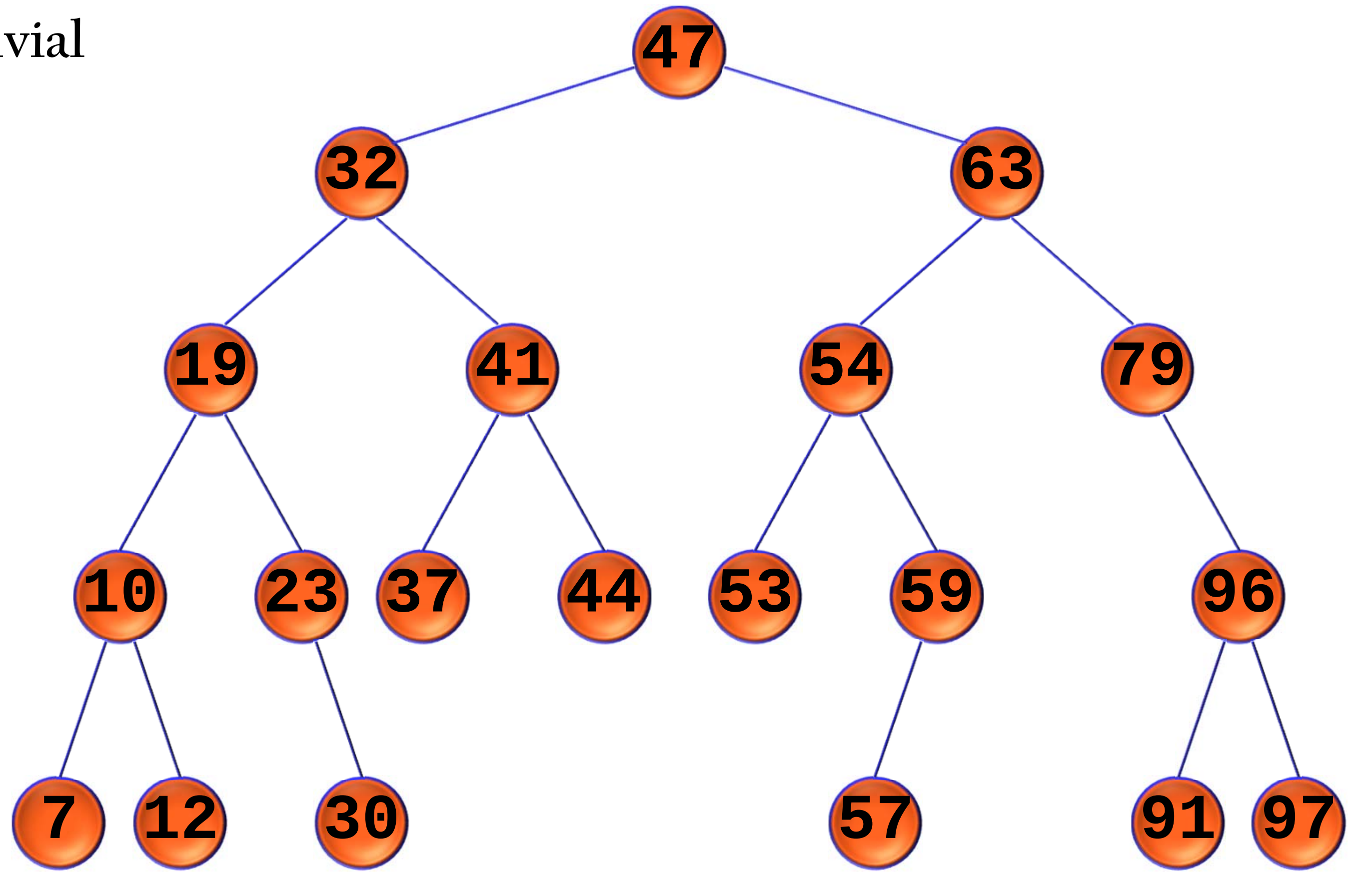
```
func insert(Value x, Node n)
if (n == null)
  return new Node(x)
if (x < n.item)
  n.right = insert(x, n.right)
if (x > n.item)
  n.left = insert(x, n.left)
return n
```

source of BST examples: J. Manuch

Deletion in BST – Case 1

Delete 30?

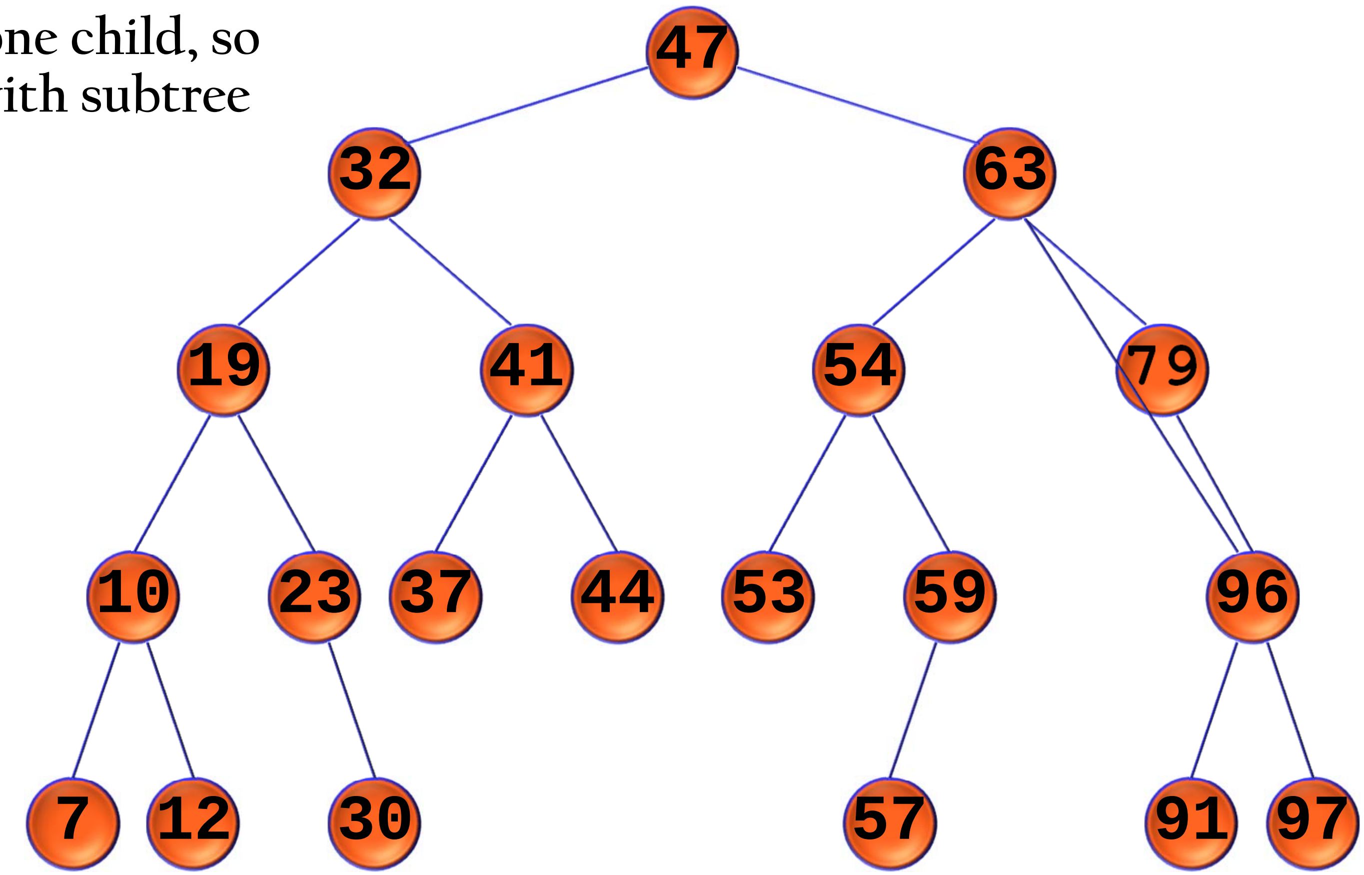
Leaf, so trivial



Deletion in BST – Case 2

Delete 79?

Easy too: one child, so replace with subtree



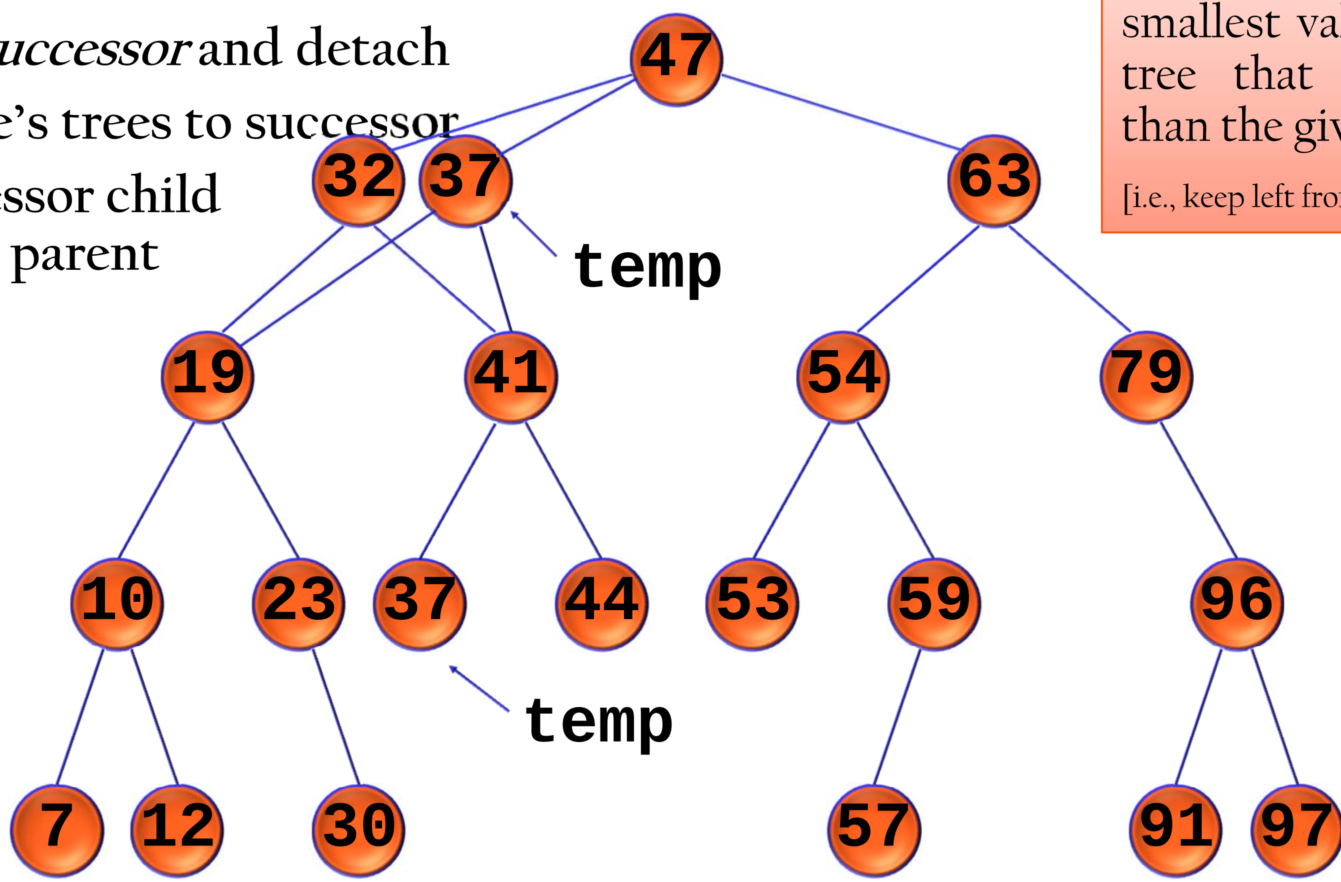
Deletion in BST – Case 3(a)

Delete 32?

first, find *successor* and detach

attach node's trees to successor

make successor child
of node's parent



The *successor* is the smallest value in the tree that is larger than the given value.

[i.e., keep left from right child]

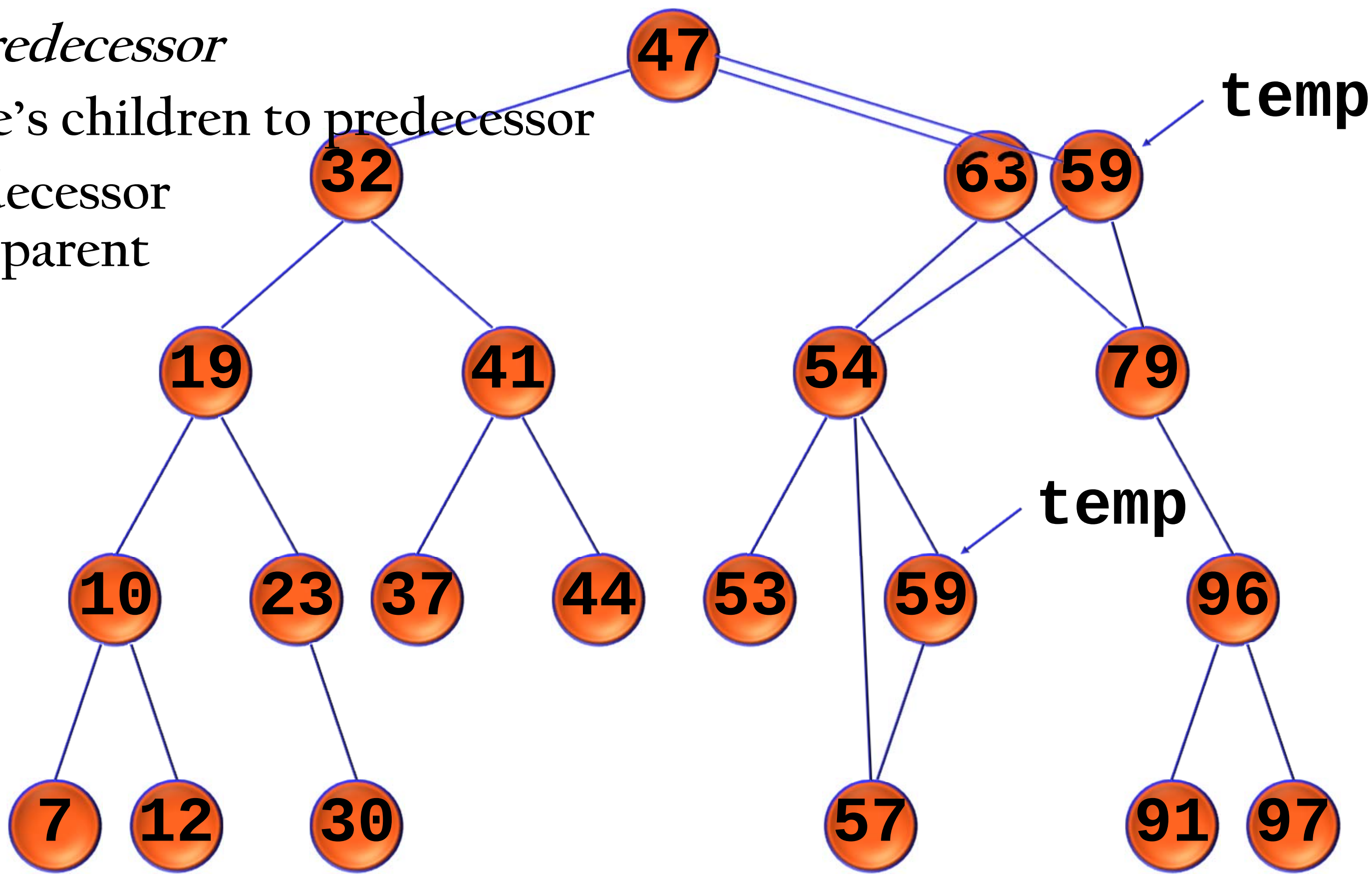
Deletion in BST – Case 3(b)

Delete 63?

shortcut *predecessor*

attach node's children to predecessor

attach predecessor
to node's parent



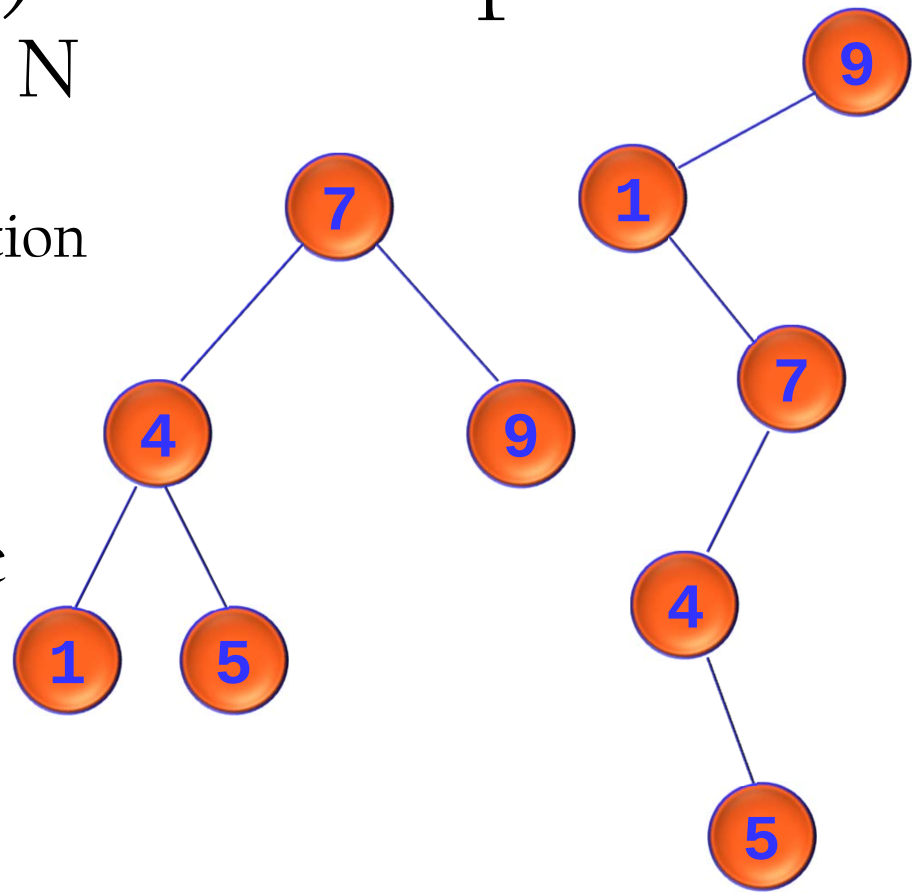
Now, What About Balancing?

Insertion (or deletion) can mess up balance

- worst case: height = N
  - bad news for cost of search/insertion/deletion

Run balancing after each operation

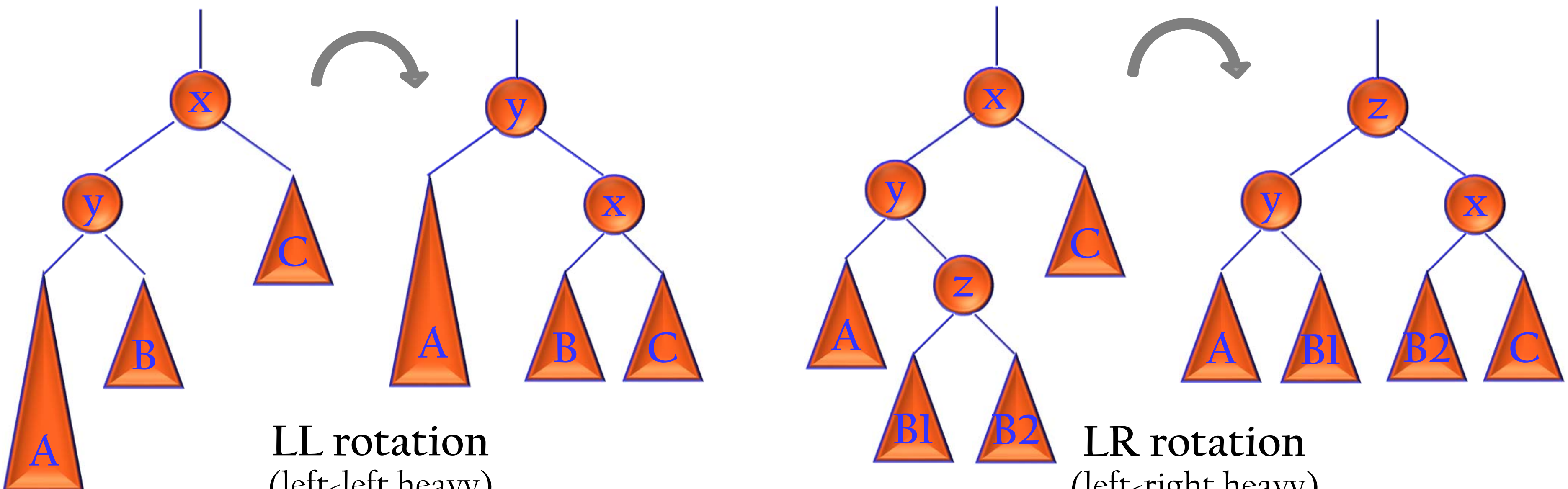
- to maintain balance
  - in O(log N)



Rebalancing

(Recursively) Check and correct balance

- only need to perform "rotations"
  - important: does not alter BST property!



LL rotation
(left-left heavy)

LR rotation
(left-right heavy)

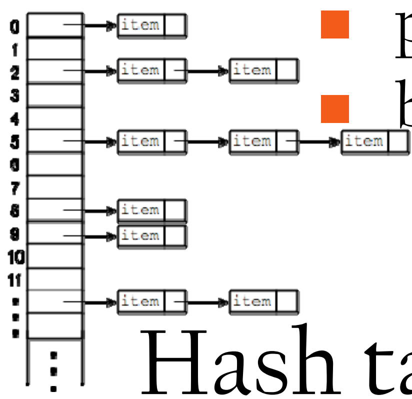
Rebalancing Pseudocode

```
IF tree is right heavy
   IF tree's right subtree is left heavy
      Perform RL rotation
   ELSE
      Perform RR rotation
ELSE IF tree is left heavy
   IF tree's left subtree is right heavy
      Perform LR rotation
   ELSE
      Perform LL rotation
```

So, Balanced BST is Best, Right?

Can do better, actually…

- if you perform lots of search
  - paying O(log n) each time is worse than… O(1)
  - but array is the only data structure with O(1) access
    - ➢ sadly, static, with size planned to be worst case scenario
      - » ex: phone numbers? 10 billions possible ones, not all used…

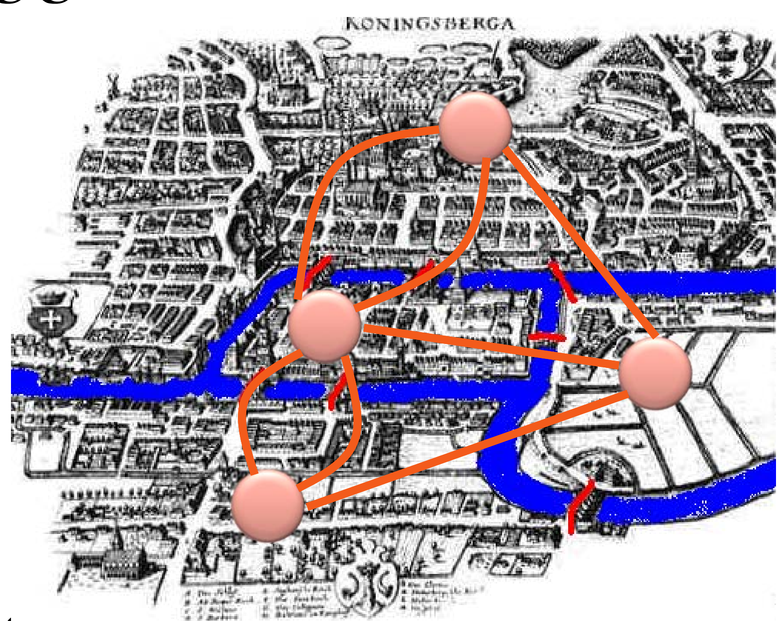


Hash tables is the answer

- roughly, array of llists with hash function
  - hash function disperses keys throughout array
  - O(1) for search, insert, and remove on average
    - ➢ but much slower to find min/max, range queries, …

Extensions of Trees

Graphs are widely used too



- date back to Euler
- nodes and links (edges)
  - cycles allowed
  - edge can be directed or not
  - values assigned to edges too
    - “weighted” graphs
- useful in many applications
  - e.g., networks, automata, database dependencies, task scheduling (critical path analysis), mapquest/google map, even garbage collection in Java