Announcements

- Study Groups for final exam
- Library: Scott Library Learning Commons
  Room: 203A
  Reservation Date: 4 Dec 2013
  Start Time: 11:30 am
- Library: Scott Library Learning Commons
  Room: 203A
  Reservation Date: 3 Dec 2013
  Start Time: 11:30 am

Announcements

- Bethune College Hiring:
- Peer Advisors, Peer Mentors, and Peer Tutors. http://bethune.yorku.ca/sos/ (http://bethune.yorku.ca/sos/) Facebook Group: Bethune College Academic Community (Photos -> Recruitment Letters)

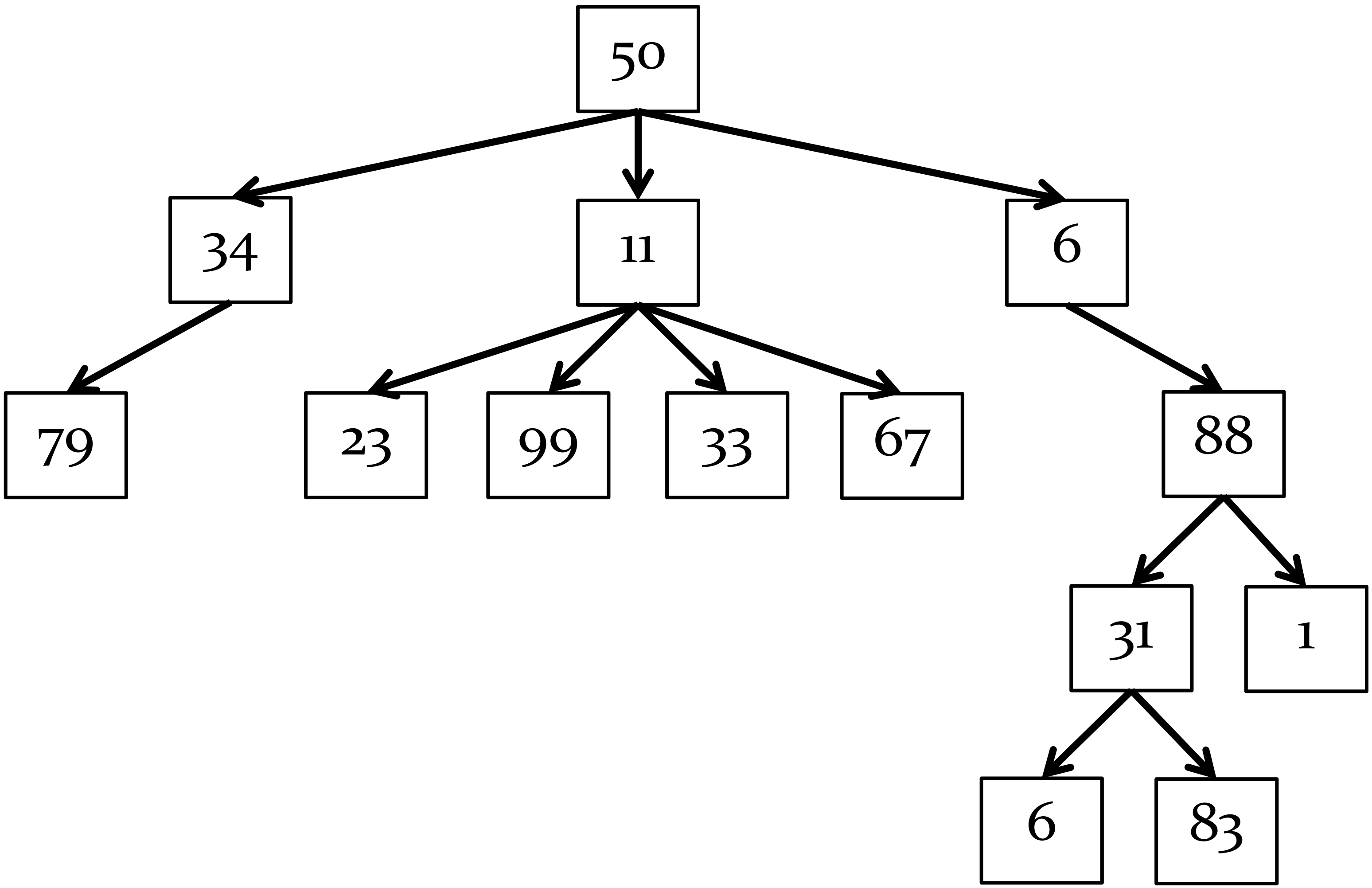
Announcements

- Dr. Renda Lenton Meeting
- November 27th at 5:30 PM in BC 320.Register Prior to attend: http://bethune.yorku.ca/events/lenton/
- Free Food. :) :) :)

Recursive Objects (Part 4)

Trees

- a tree is a data structure made up of nodes
  - each node stores data
  - each node has links to zero or more nodes in the next level of the tree
    - children of the node
  - each node has exactly one parent node
    - except for the root node


50
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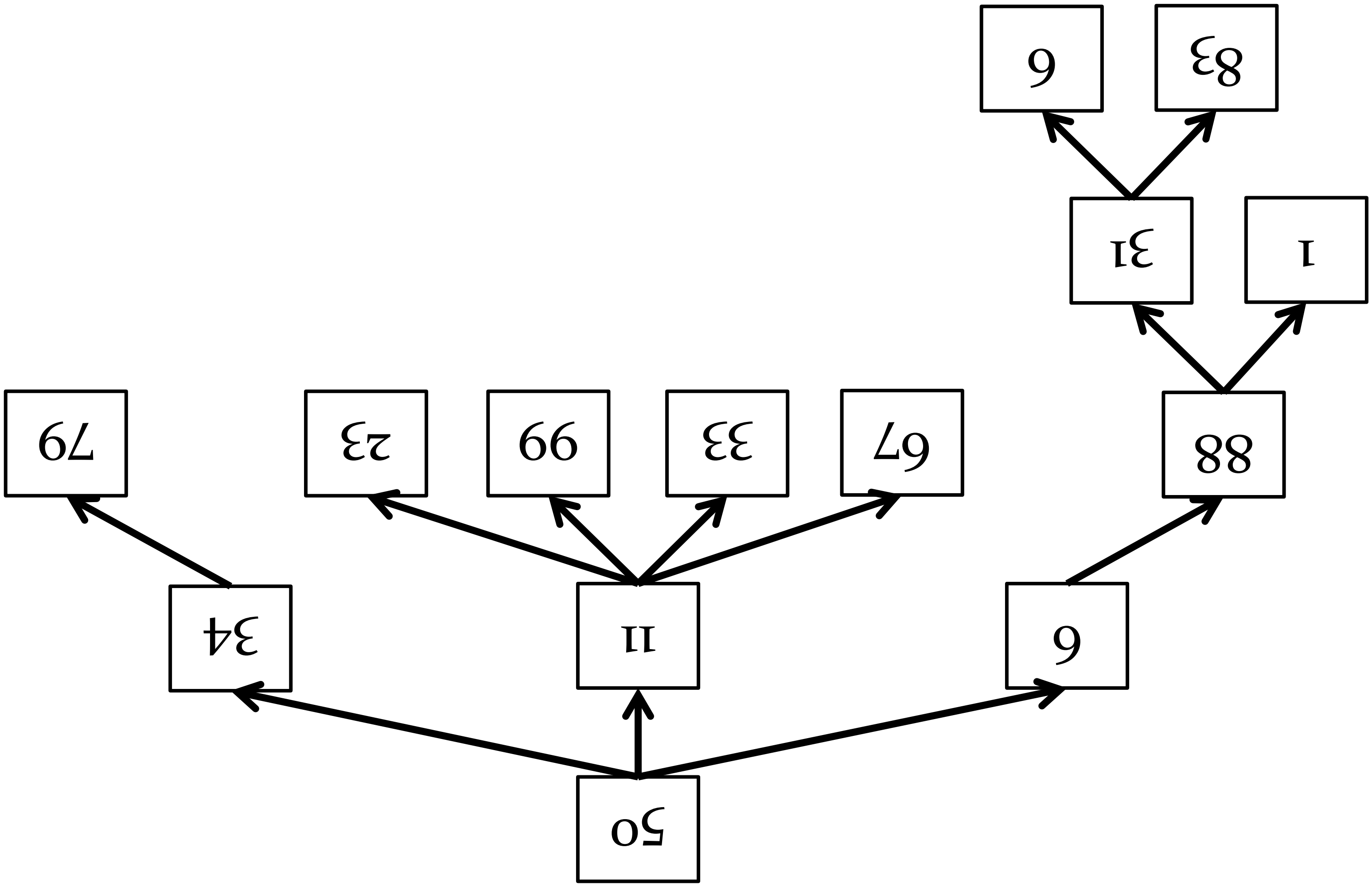
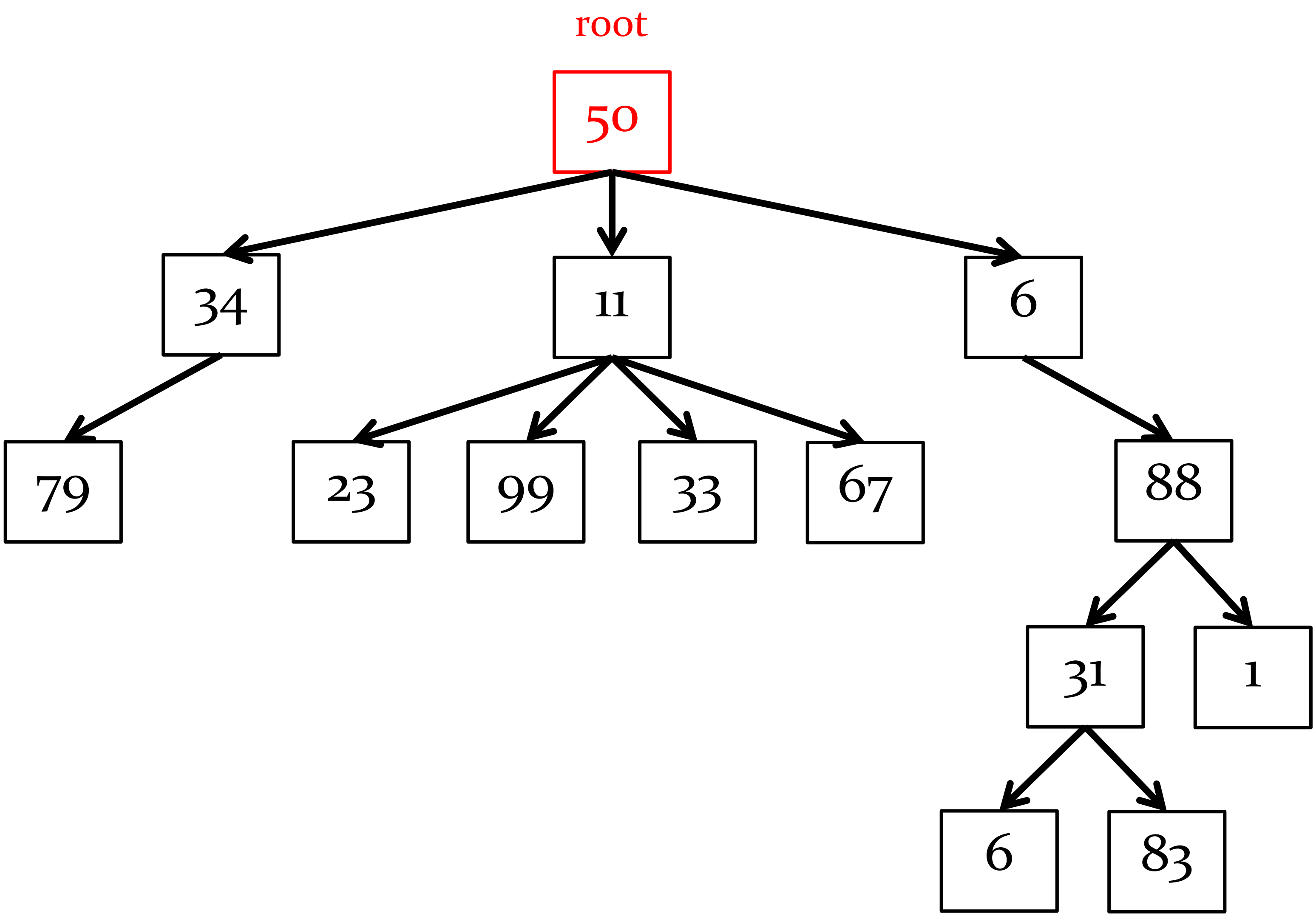


Trees

- the root of the tree is the node that has no parent node
- all algorithms start at the root


root
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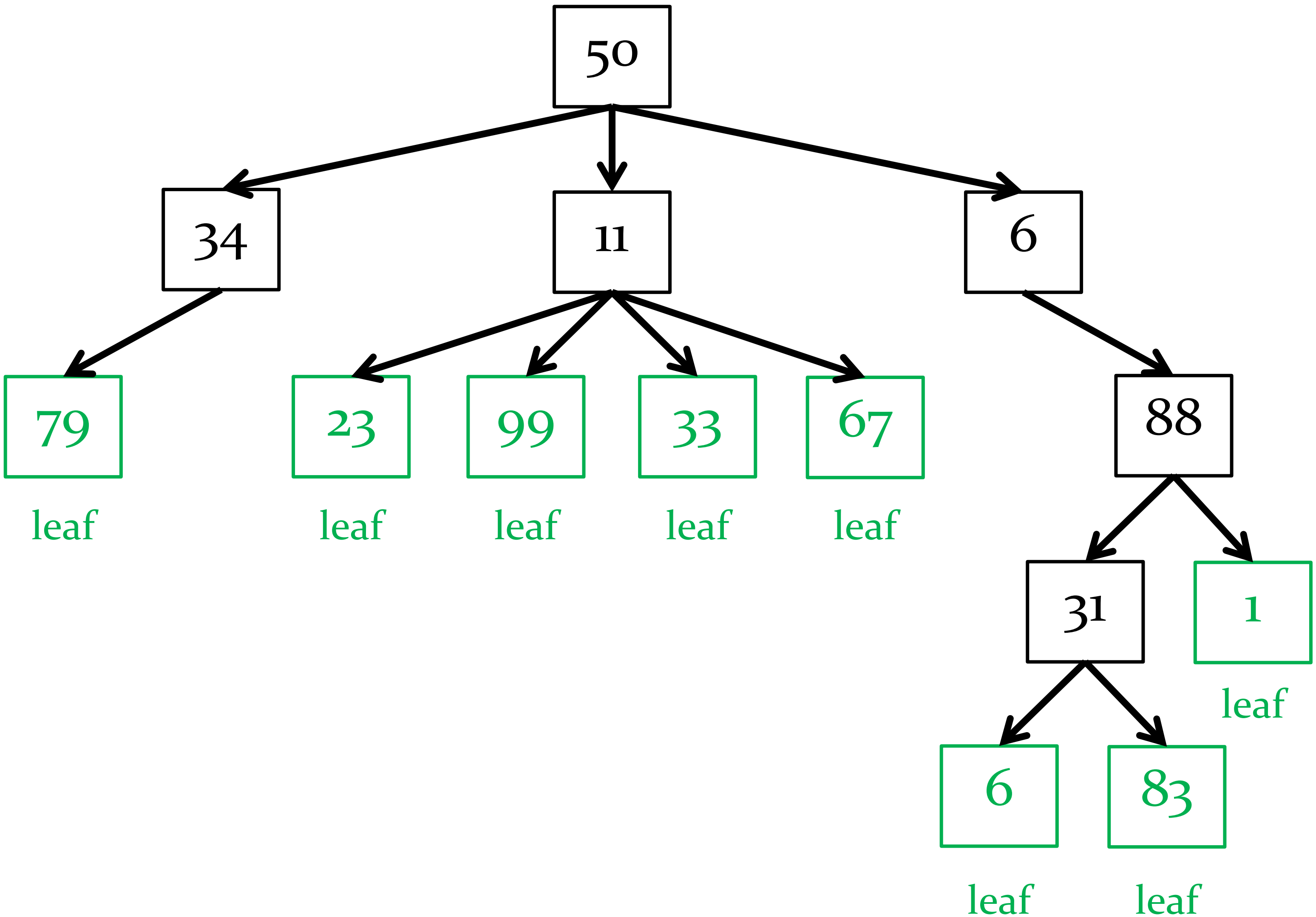
33
67
88
31
1
6
83

Trees

- a node without any children is called a leaf


50
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23
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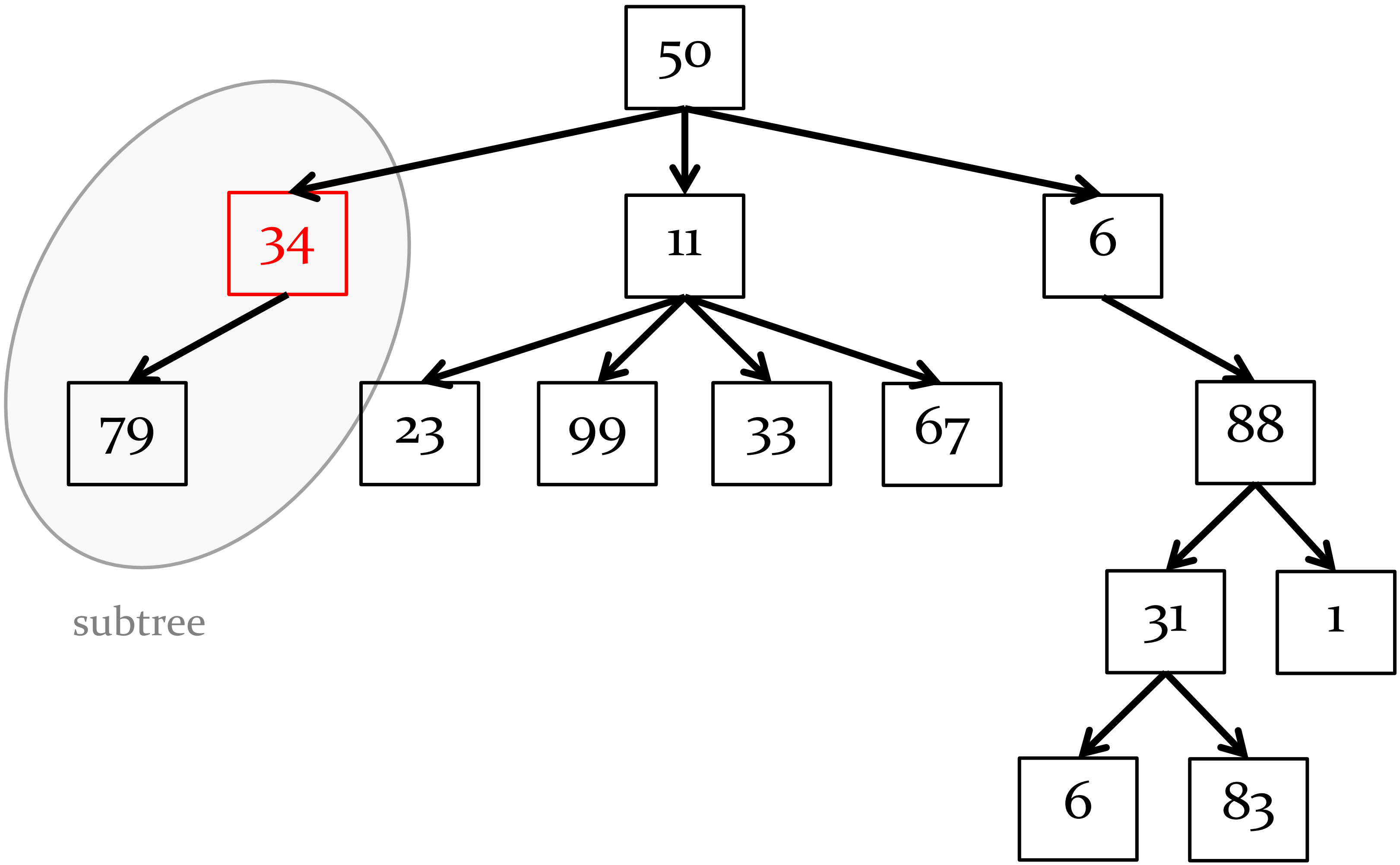
33
67
88
leaf
leaf
leaf
leaf
leaf
31
1
leaf
6
83
leaf
leaf

Trees

- the recursive structure of a tree means that every node is the root of a tree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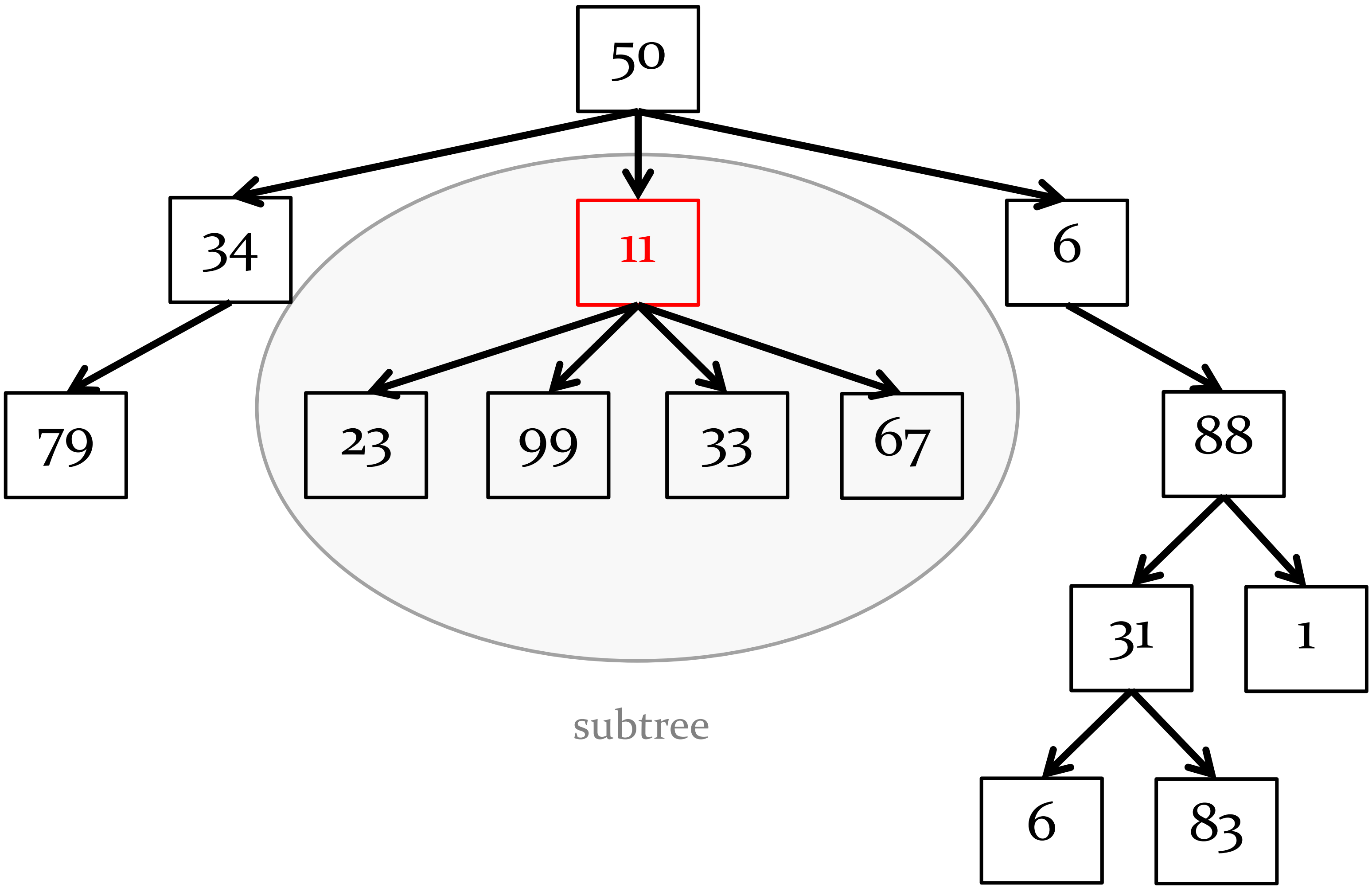
83
subtree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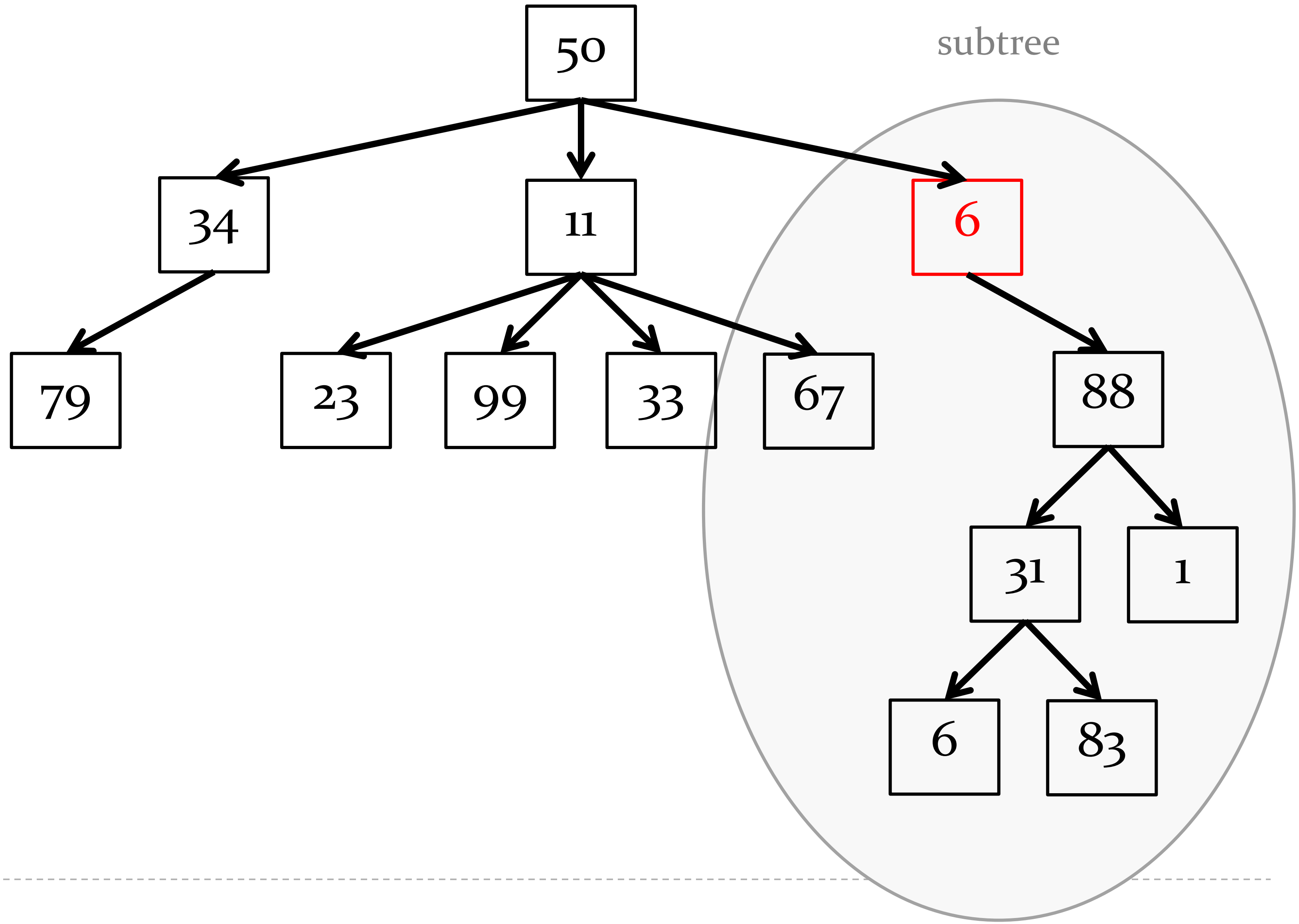
83
subtree


subtree
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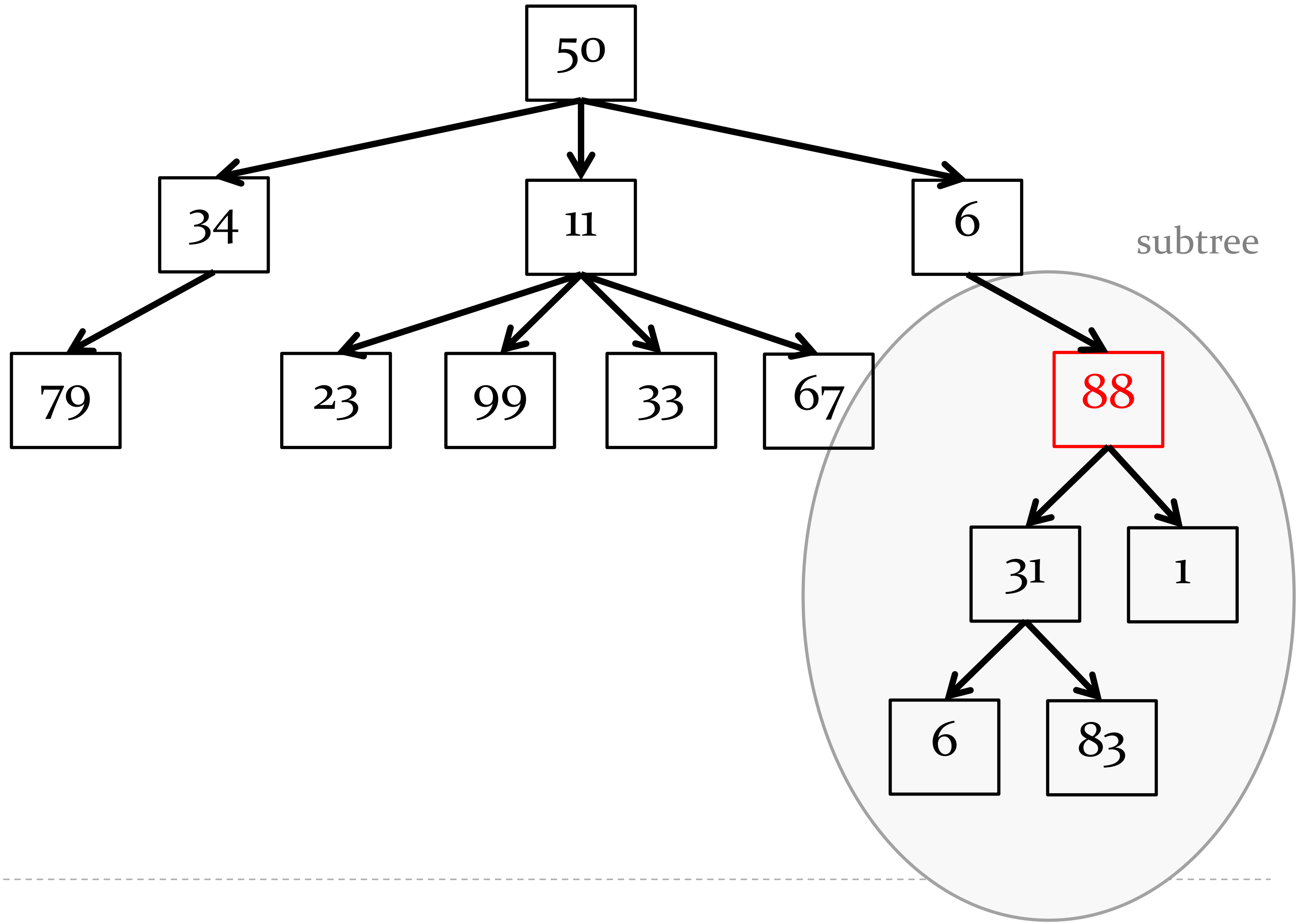
50
34
11
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subtree
79
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99
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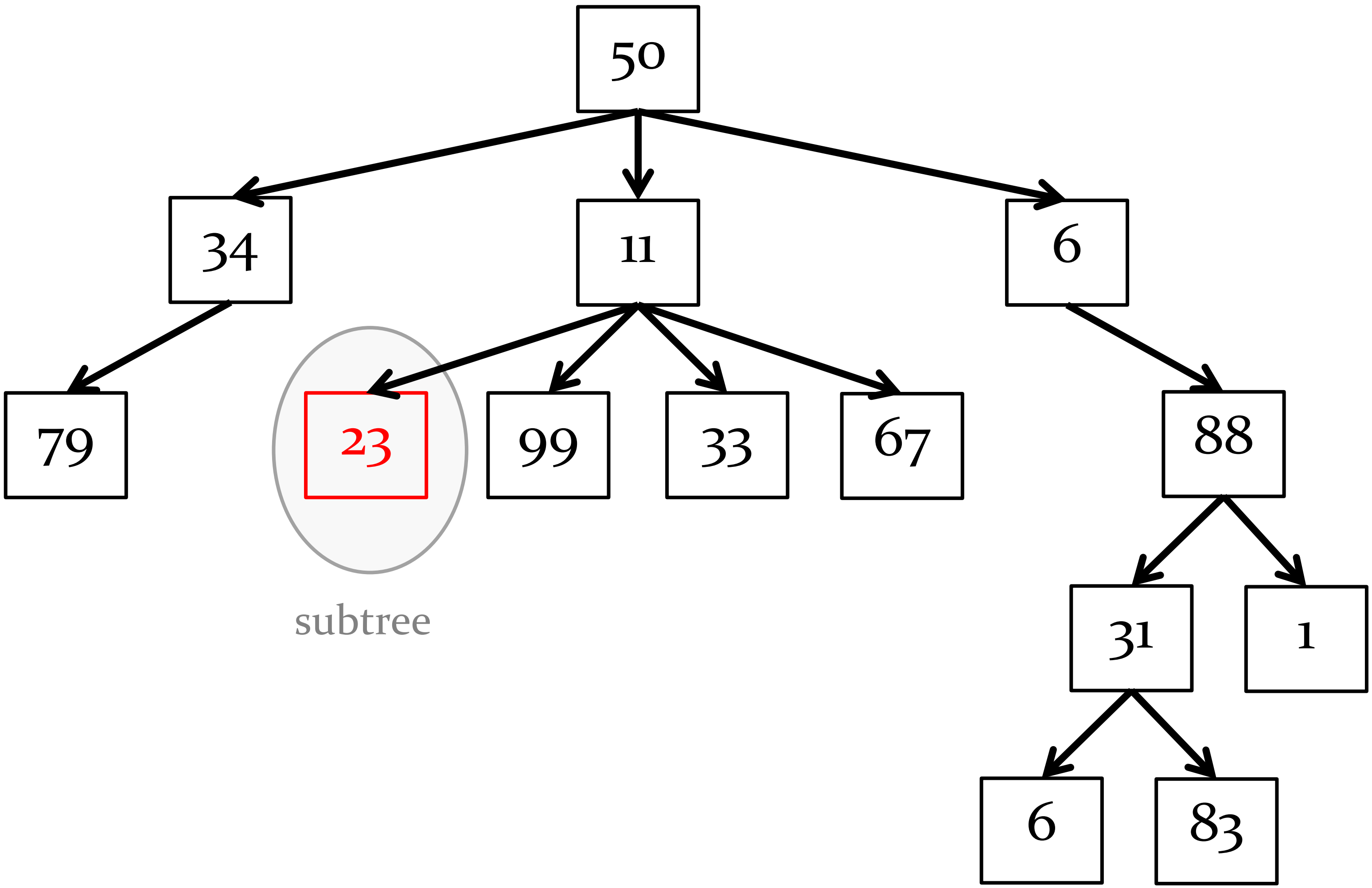
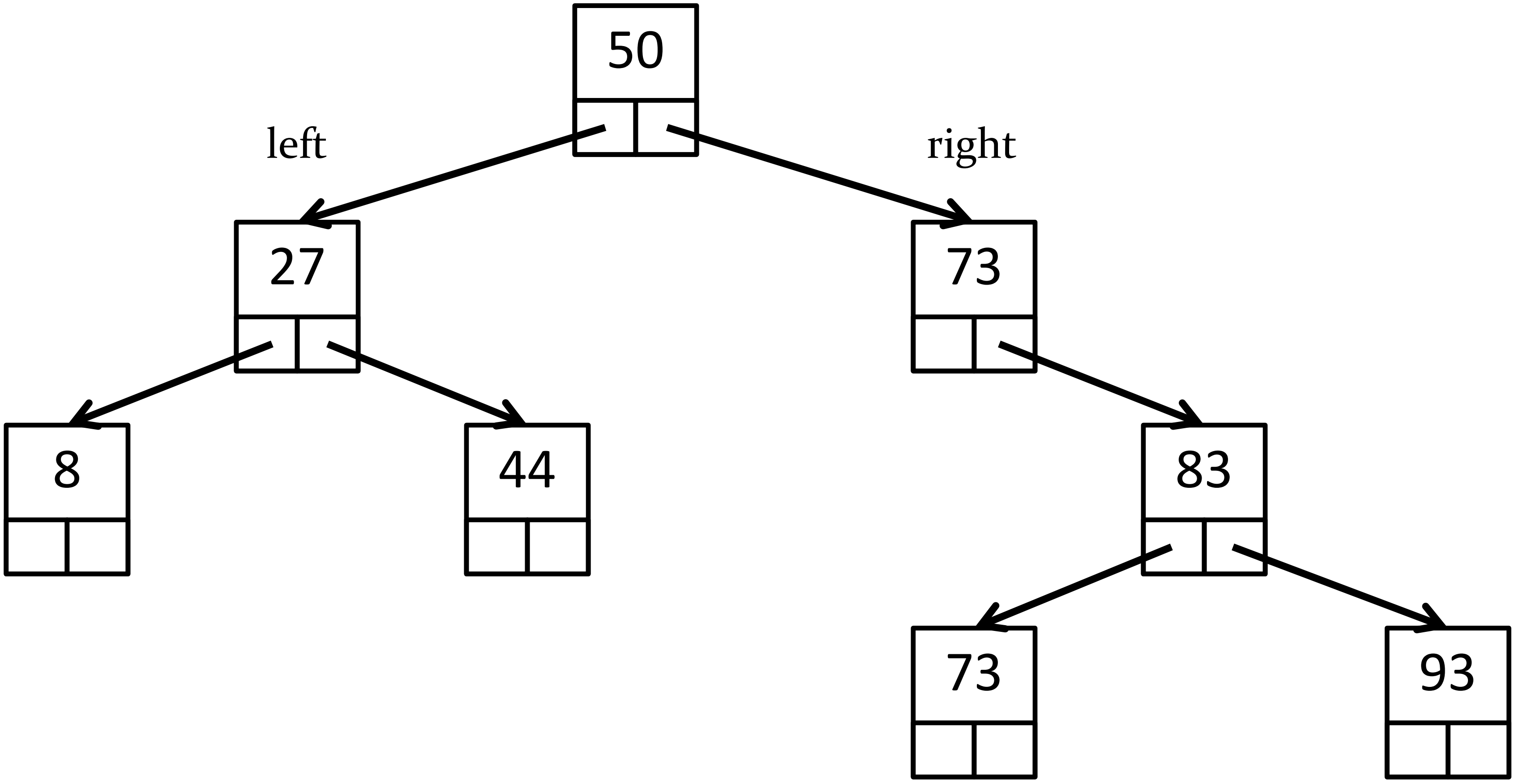
67
88
31
1
6
83

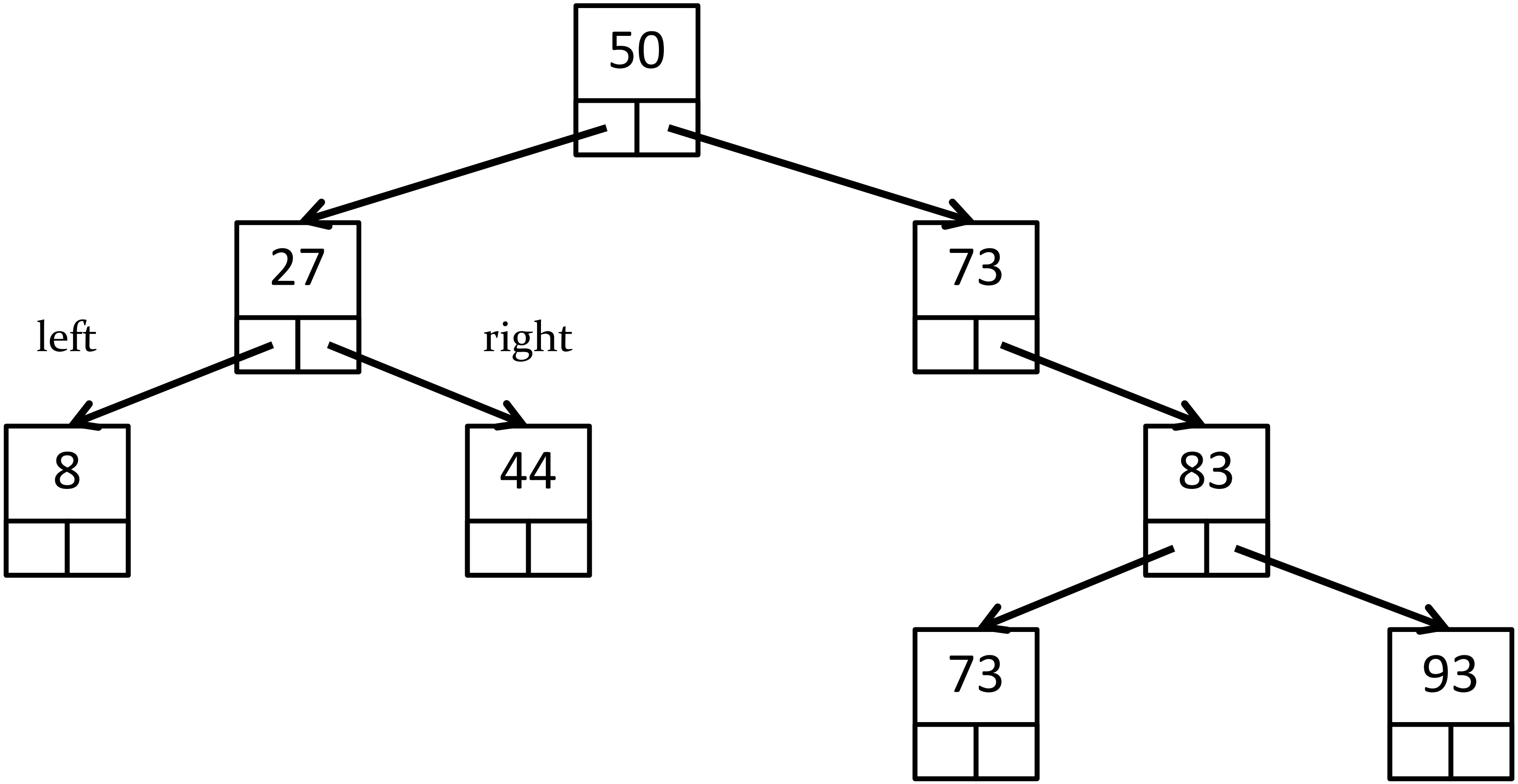

50
34
11
6
79
23
99
33
67
88
31
1
6
83
subtree

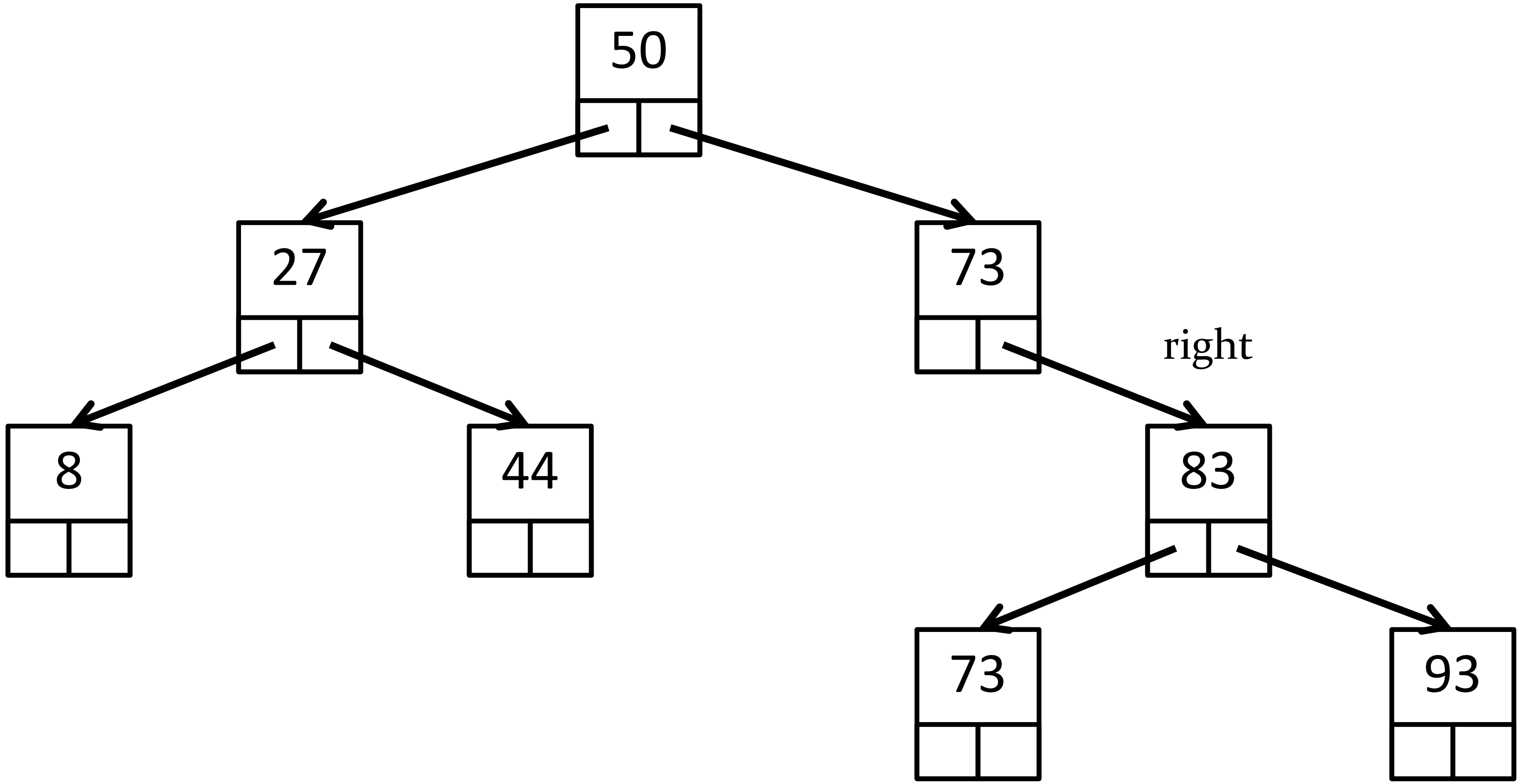
Binary Tree

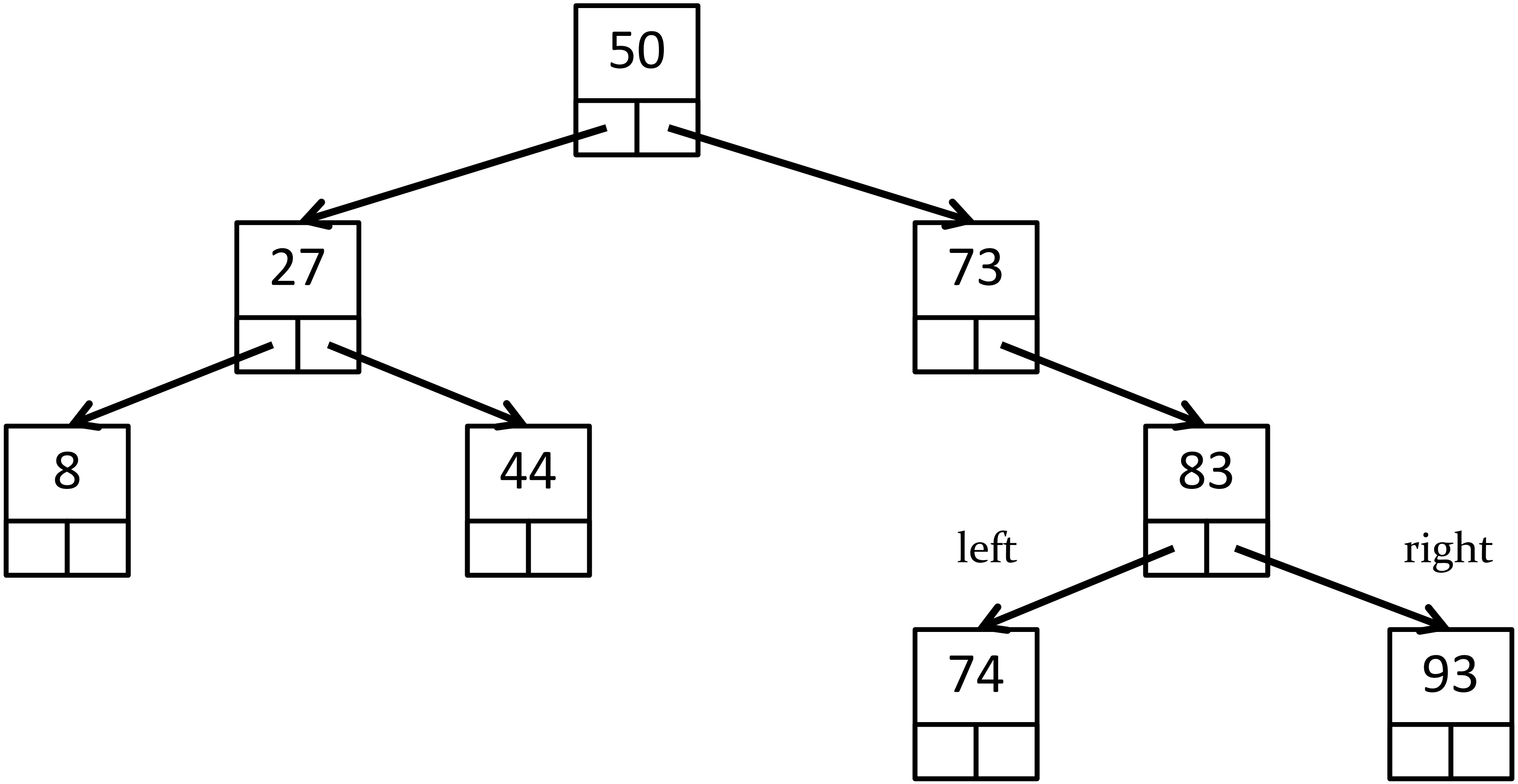
- a binary tree is a tree where each node has at most two children
  - very common in computer science
  - many variations
- traditionally, the children nodes are called the left node and the right node



50
left
right
27
73
8
44
83
73
93


50
27
73
left
right
8
44
83
73
93


50
27
73
right
8
44
83
73
93



50
27
73
8
44
83
left
right
74
93

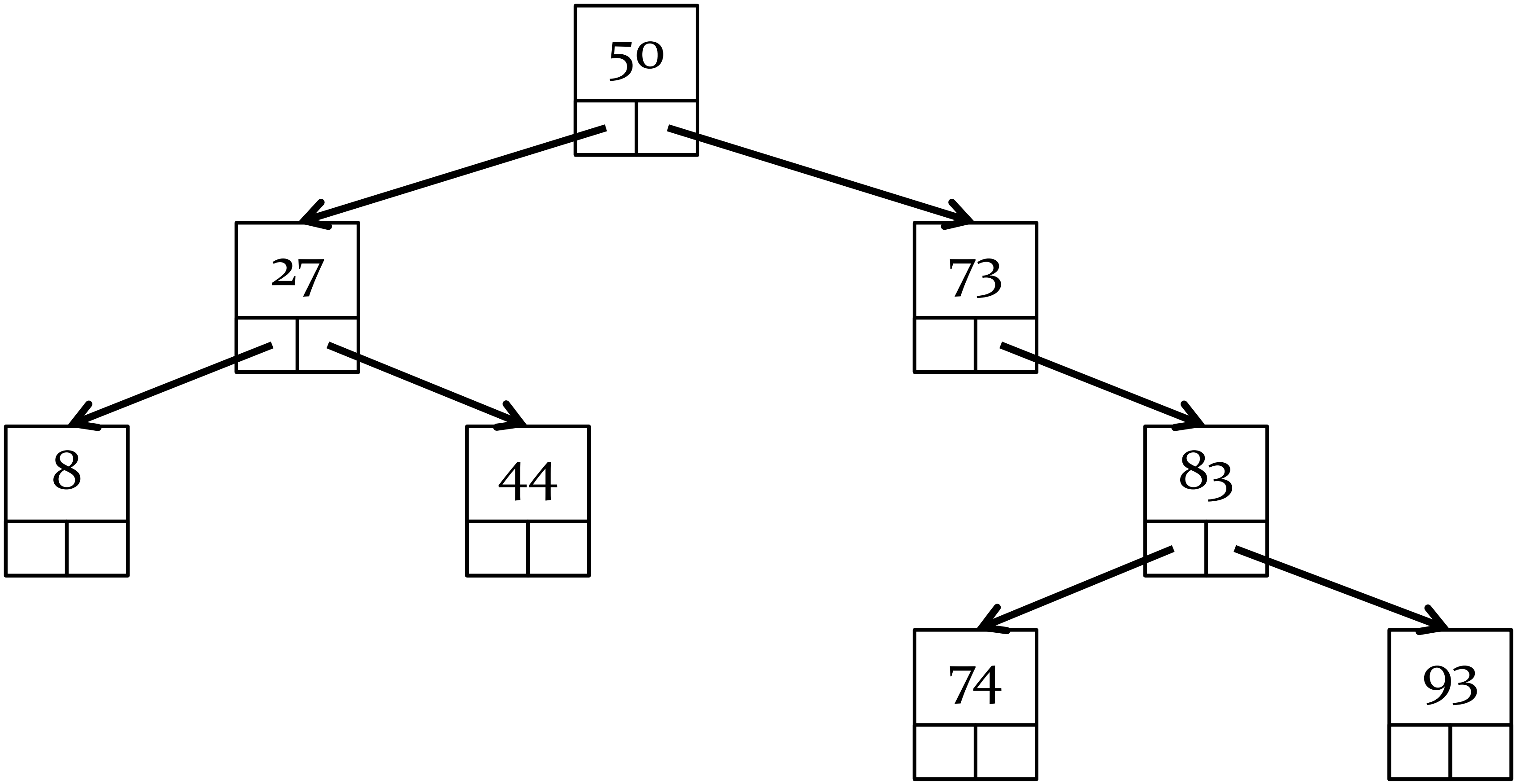
Binary Tree Algorithms

- the recursive structure of trees leads naturally to recursive algorithms that operate on trees
- for example, suppose that you want to search a binary tree for a particular element

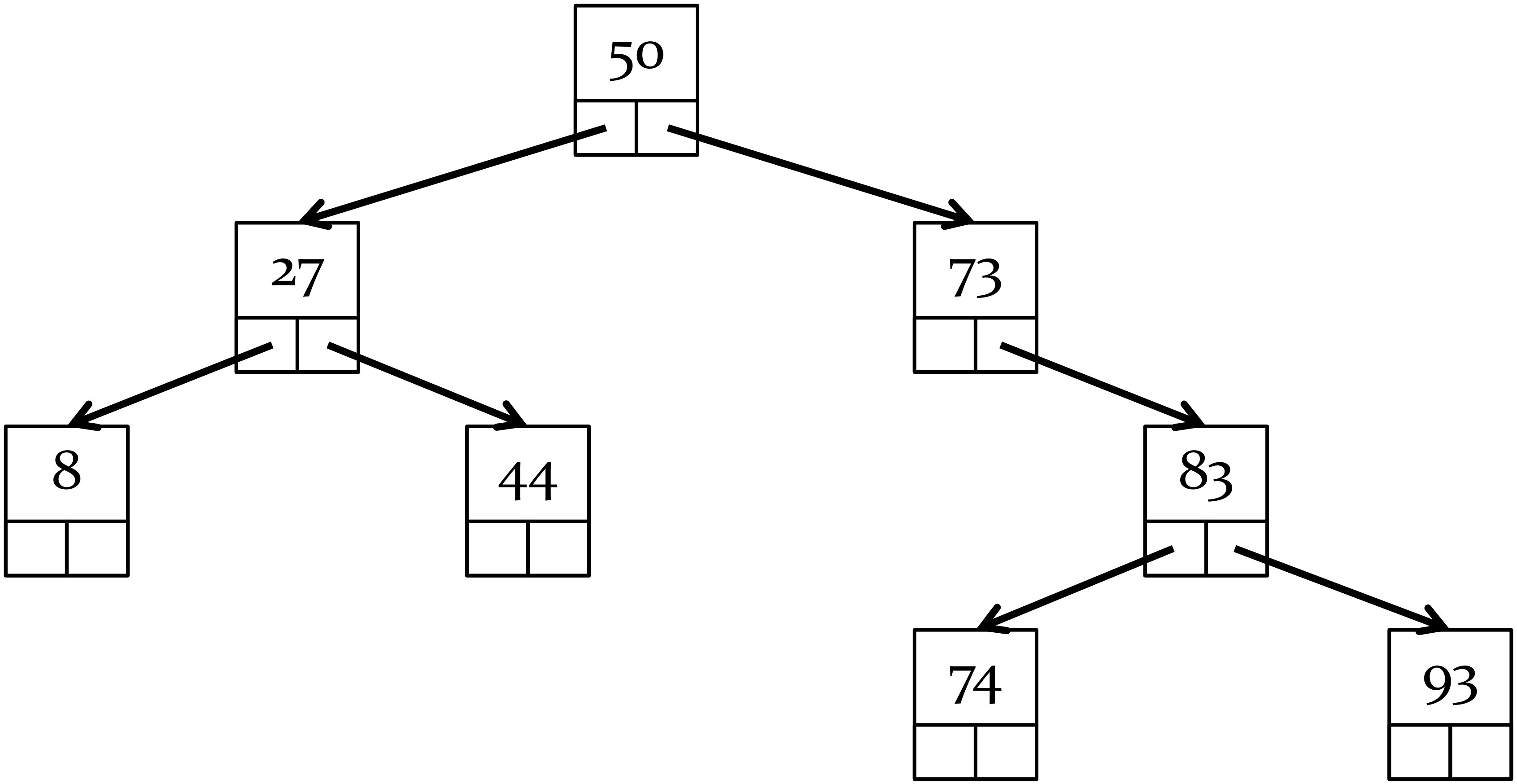
```java
public static <E> boolean contains(E element, Node<E> node) {
  if (node == null) {
    return false;
  }
  if (element.equals(node.data)) {
    return true;
  }
  boolean inLeftTree = contains(element, node.left);
  if (inLeftTree) {
    return true;
  }
  boolean inRightTree = contains(element, node.right);
  return inRightTree;
}
```

Iteration

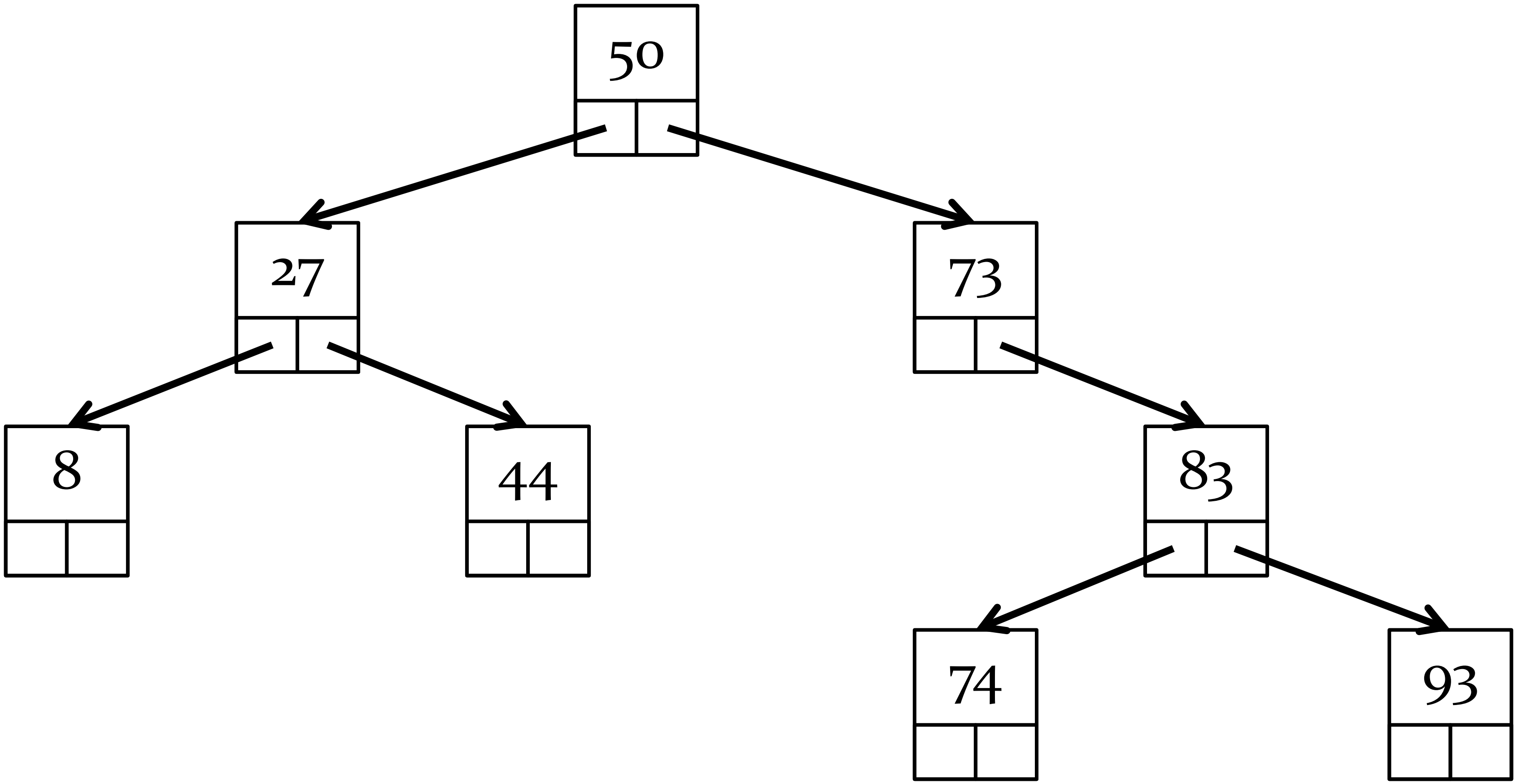
- visiting every element of the tree can also be done recursively
- 3 possibilities based on when the root is visited
  - inorder
    - visit left child, then root, then right child
  - preorder
    - visit root, then left child, then right child
  - postorder
    - visit left child, then right child, then root



inorder: 8, 27, 44, 50, 73, 74, 83, 93



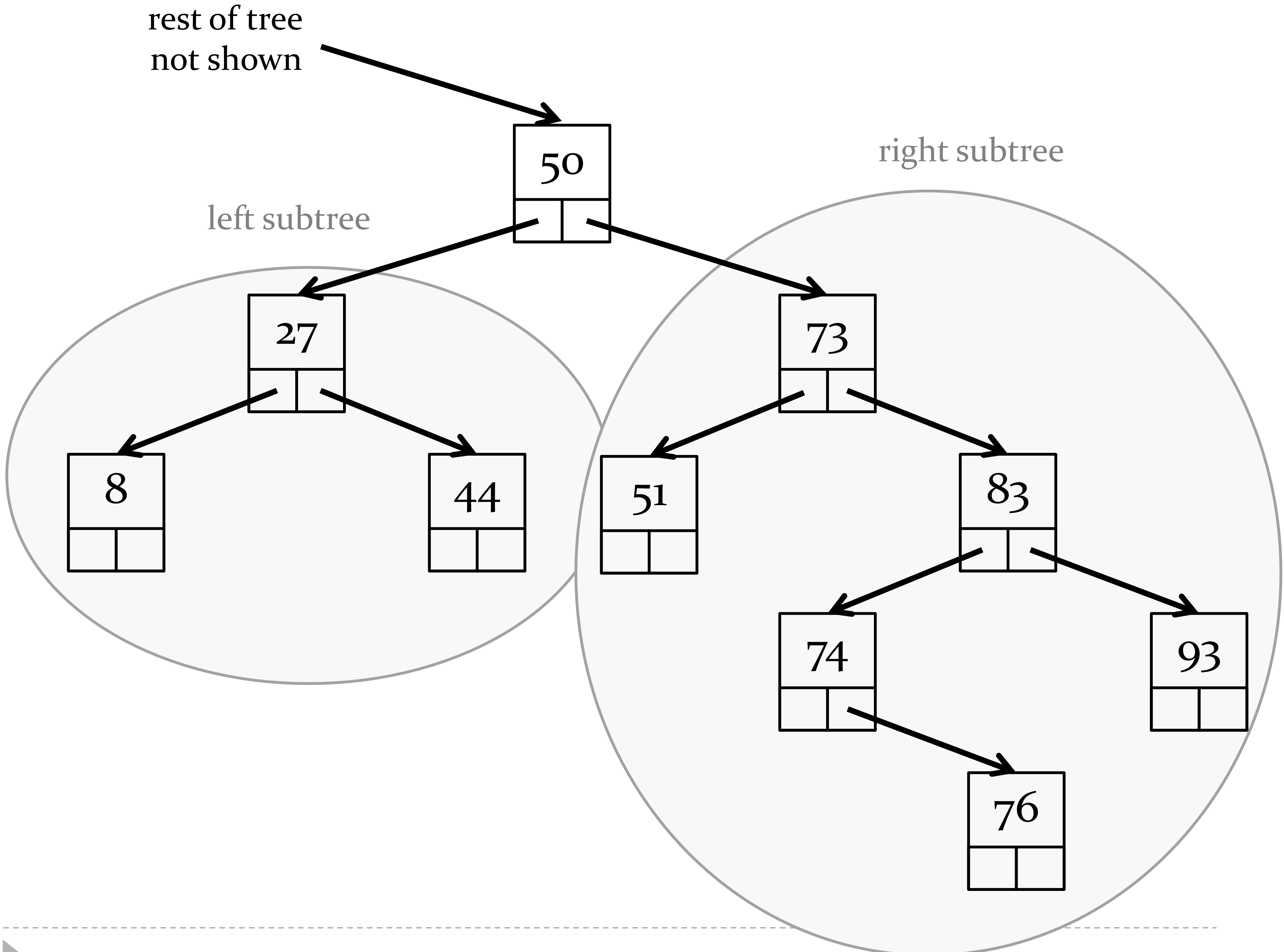
preorder: 50, 27, 8, 44, 73, 83, 74, 93



postorder: 8, 44, 27, 74, 93, 83, 73, 50

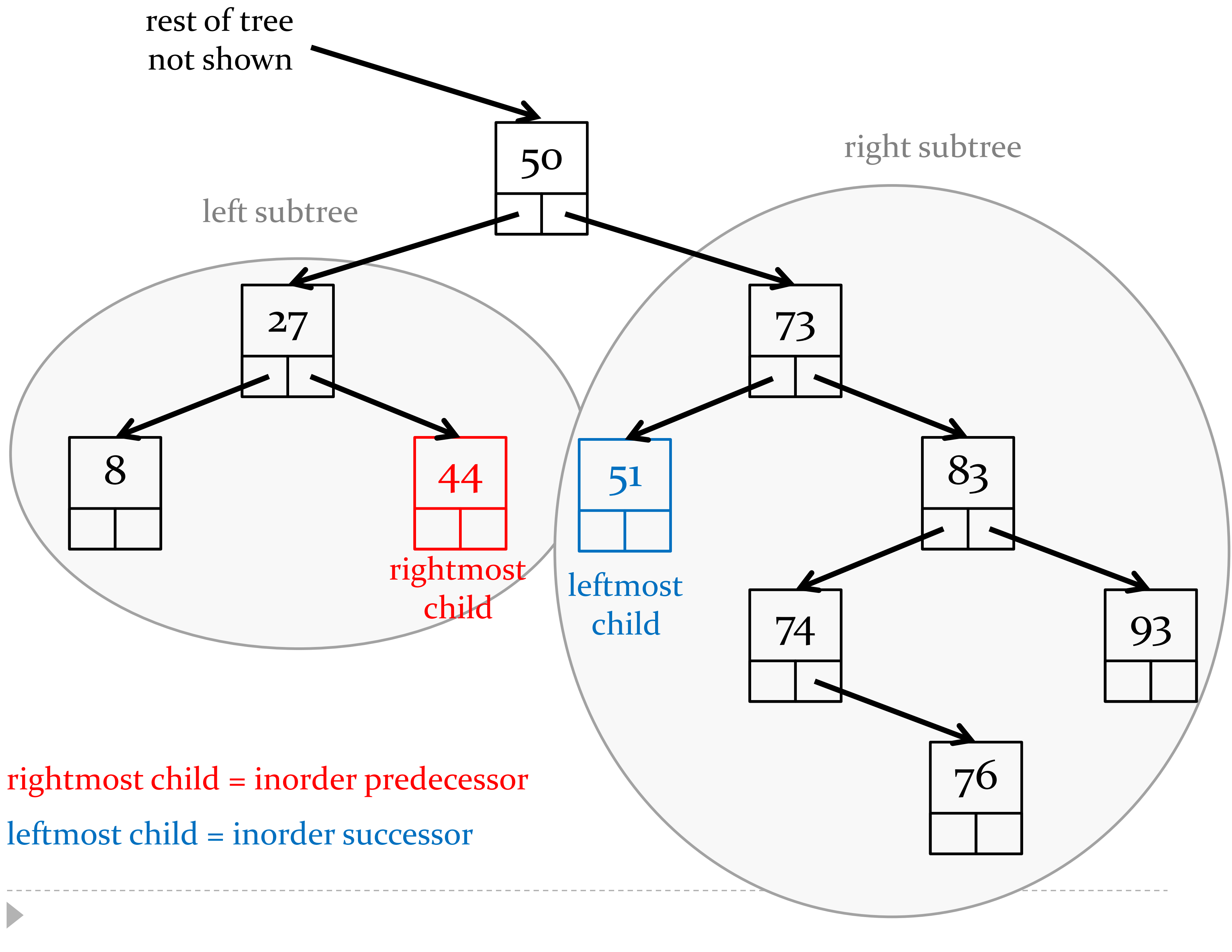
Binary Search Trees (BST)

- the tree from the previous slide is a special kind of binary tree called a *binary search tree*
- in a binary search tree:
  1. all nodes in the left subtree have data elements that are less than the data element of the root node
  2. all nodes in the right subtree have data elements that are greater than the data element of the root node
  3. rules 1 and 2 apply recursively to every subtree


rest of tree
not shown
right subtree
left subtree
50
27
73
8
44
51
83
74
93
76

Predecessors and Successors in a BST

- in a BST there is something special about a node's:
  - left subtree right-most child
  - right subtree left-most child


rest of tree
not shown
50
right subtree
left subtree
27
73
8
44
rightmost
child
51
leftmost
child
83
74
93
76
rightmost child = inorder predecessor
leftmost child = inorder successor

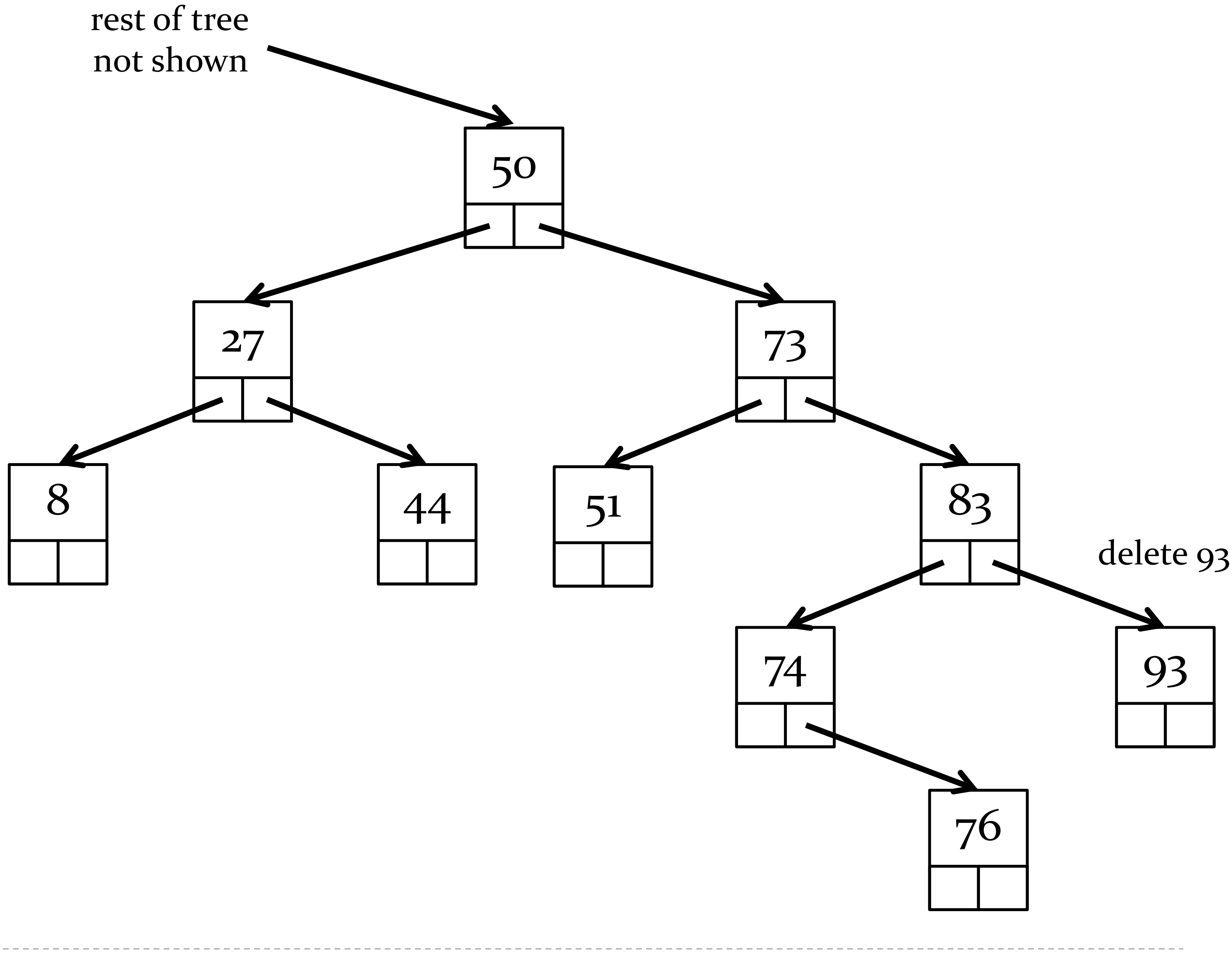
Deletion from a BST

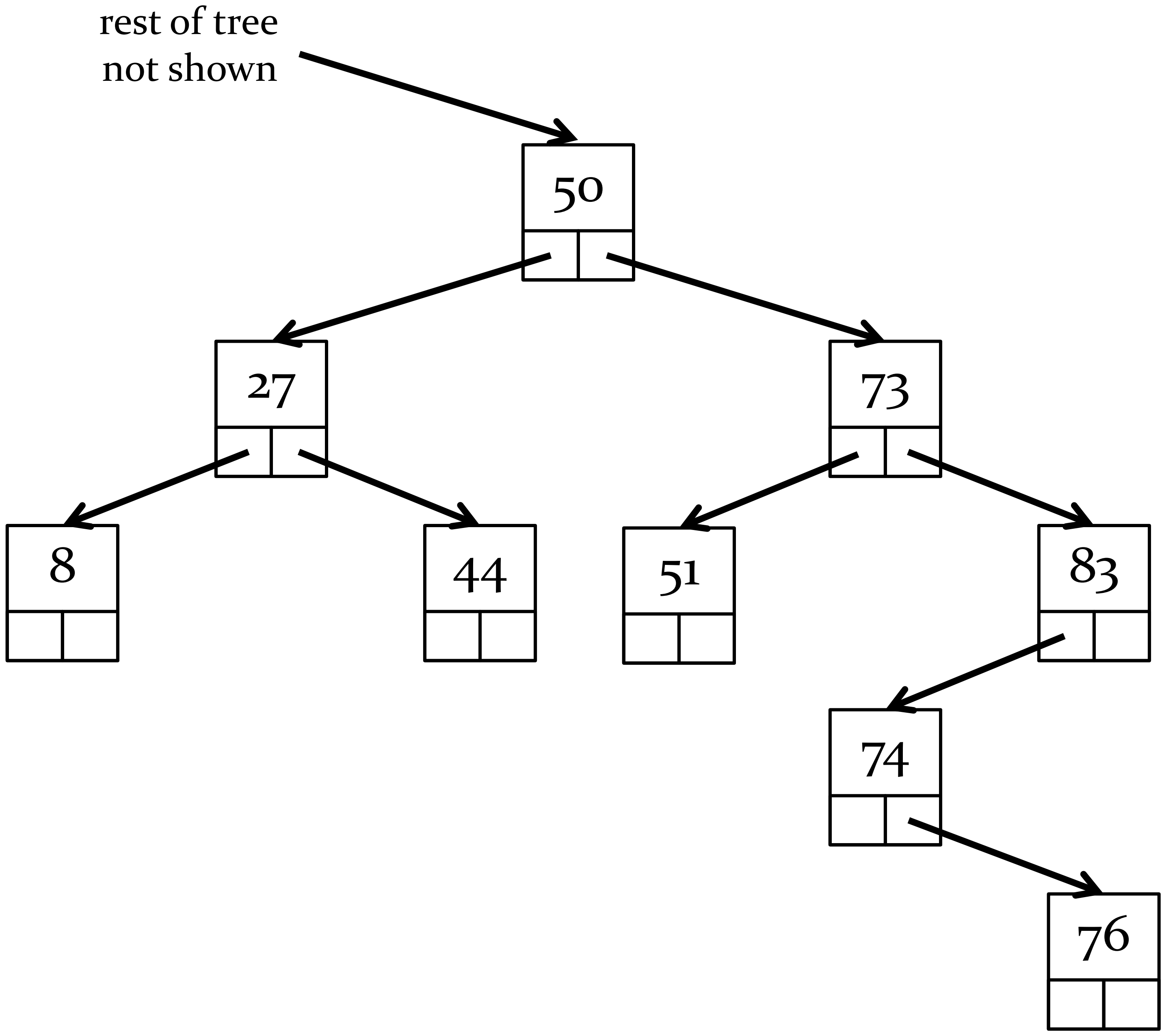
- to delete a node in a BST there are 3 cases to consider:
  1. deleting a leaf node
  2. deleting a node with one child
  3. deleting a node with two children

Deleting a Leaf Node

- deleting a leaf node is easy because the leaf has no children
  - simply remove the node from the tree

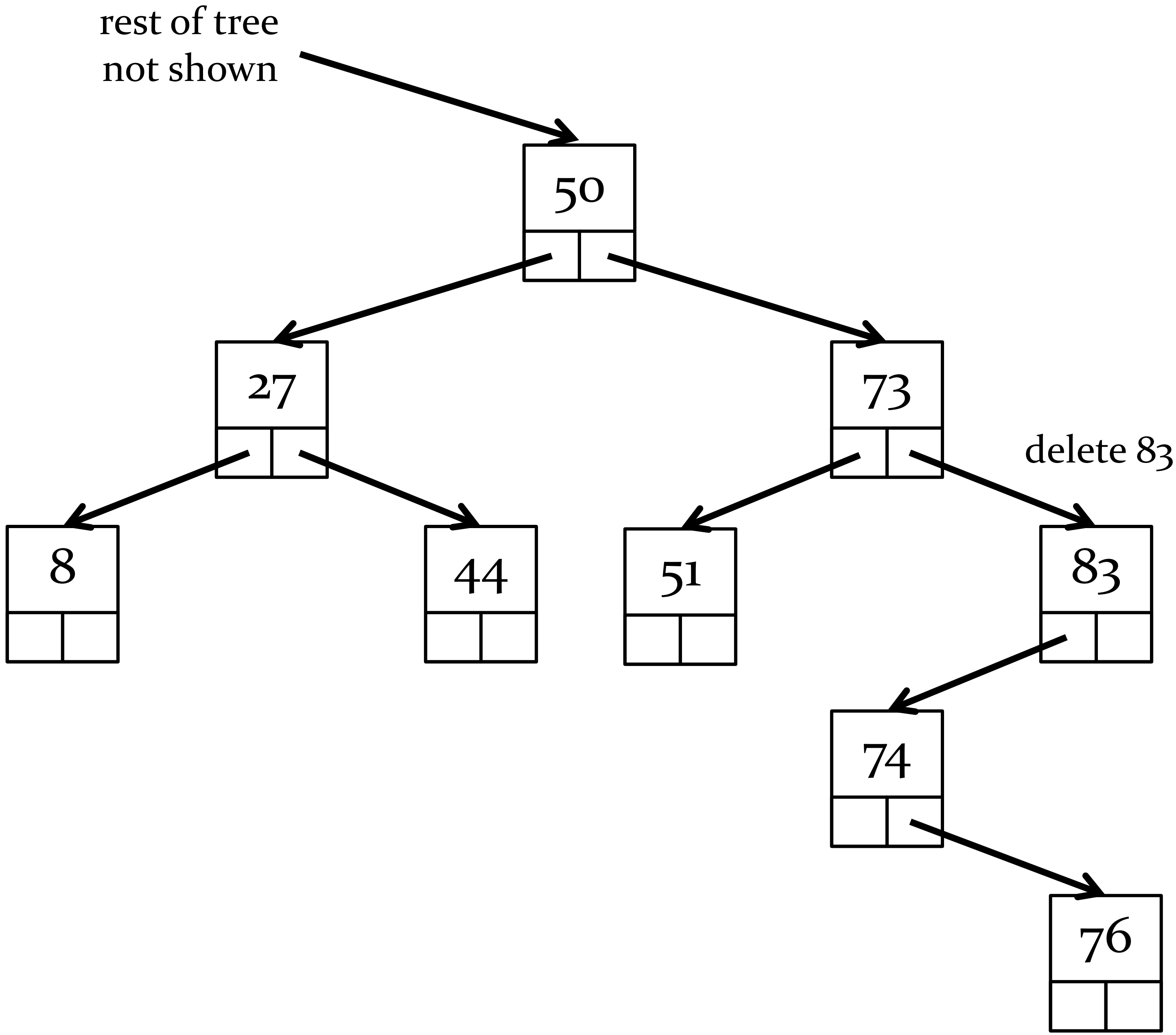
- e.g., delete 93

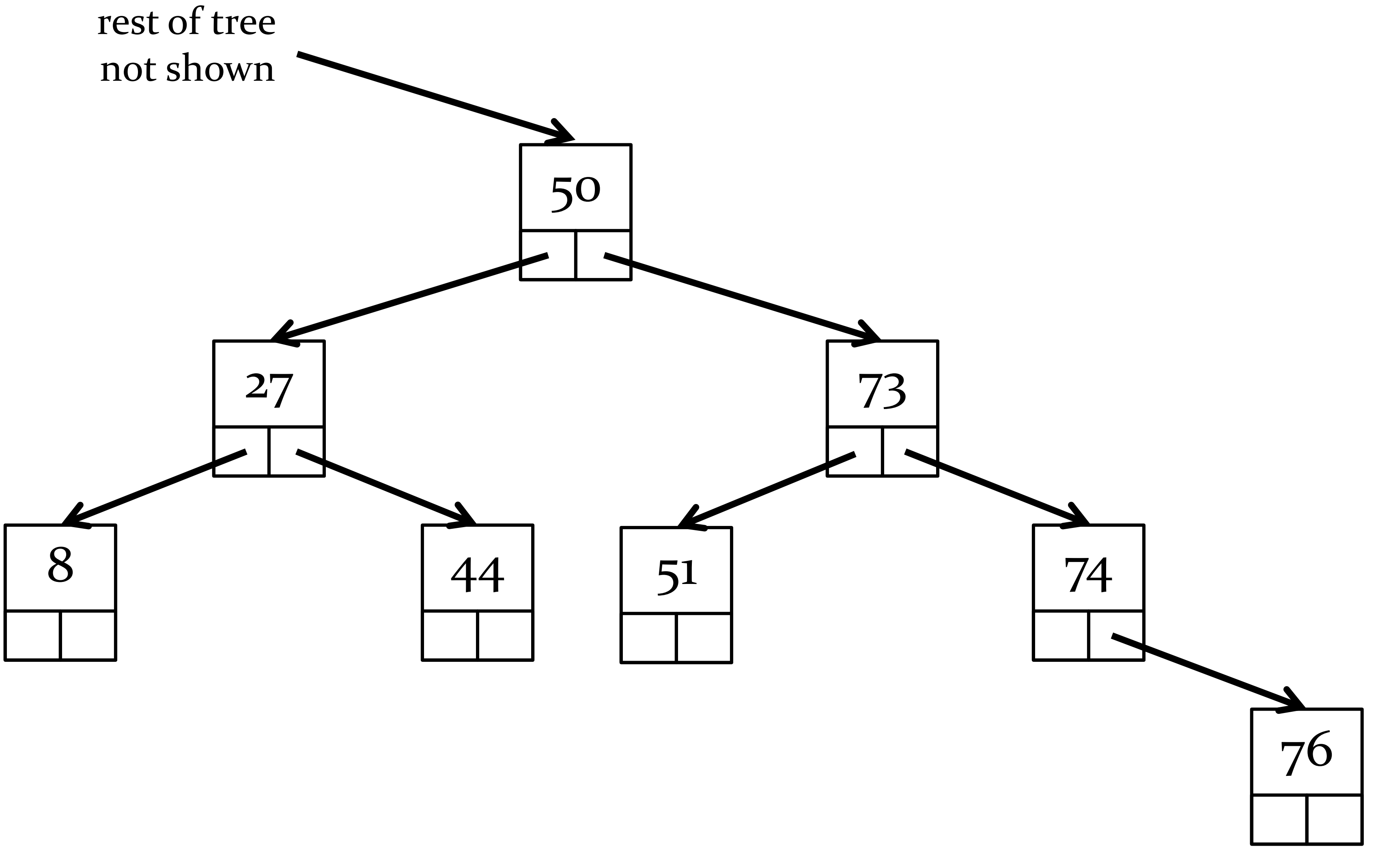

rest of tree
not shown
50
27
73
8
44
51
83
delete 93
74
93
76


rest of tree
not shown
50
27
73
8
44
51
83
74
76

Deleting a Node with One Child

- deleting a node with one child is also easy because of the structure of the BST
  - remove the node by replacing it with its child
- e.g., delete 83

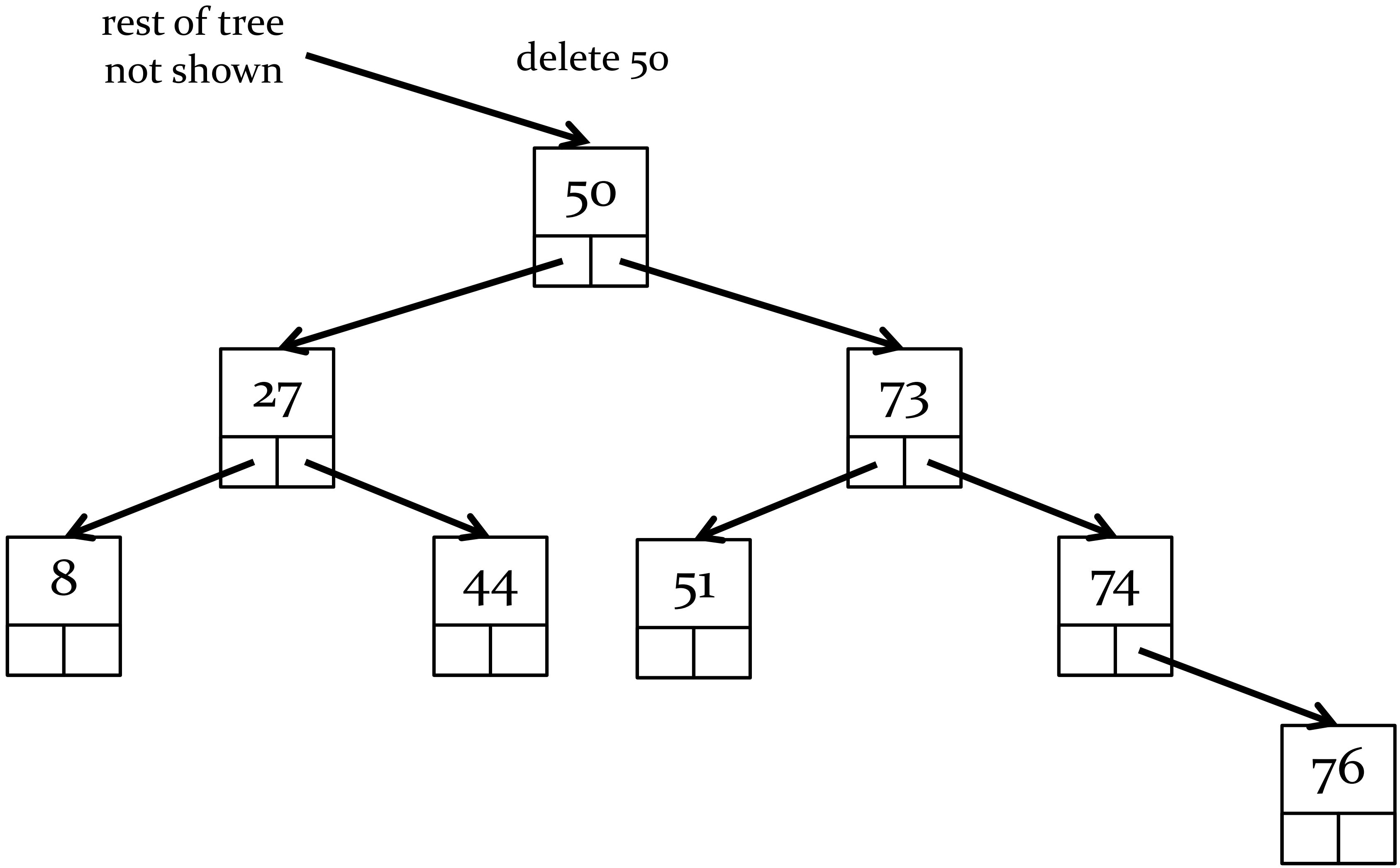

rest of tree
not shown
50
27
73
delete 83
8
44
51
83
74
76


rest of tree
not shown
50
27
73
8
44
51
74
76

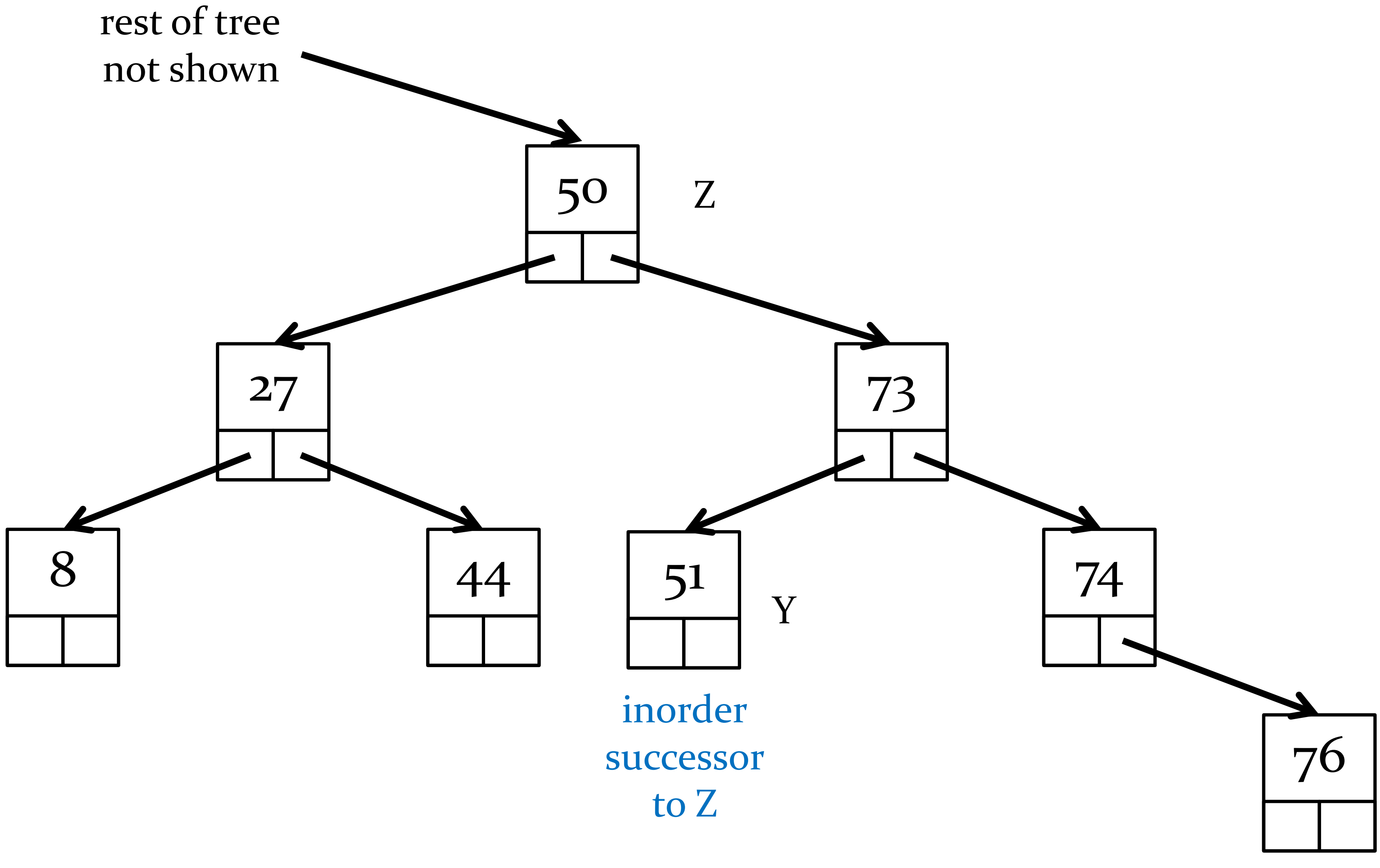
Deleting a Node with Two Children

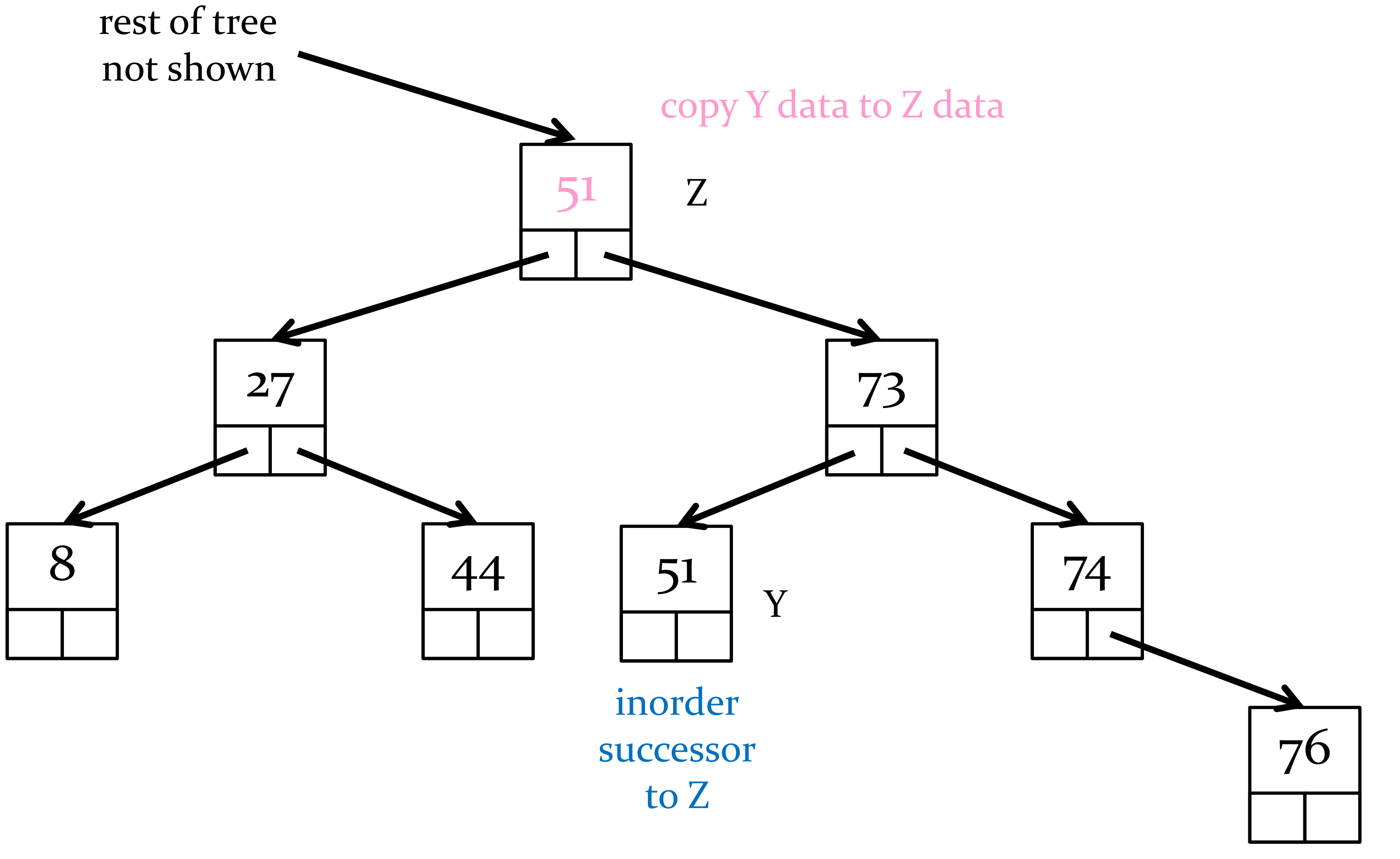
- deleting a node with two children is a little trickier
  - call the node to be deleted Z
  - find the inorder predecessor OR the inorder successor
    - call this node Y
      - if the inorder predecessor does not exist, then you must find the inorder successor (and vice versa)
  - copy the data element of Y into the data element of Z
  - delete Y

- e.g., delete 50

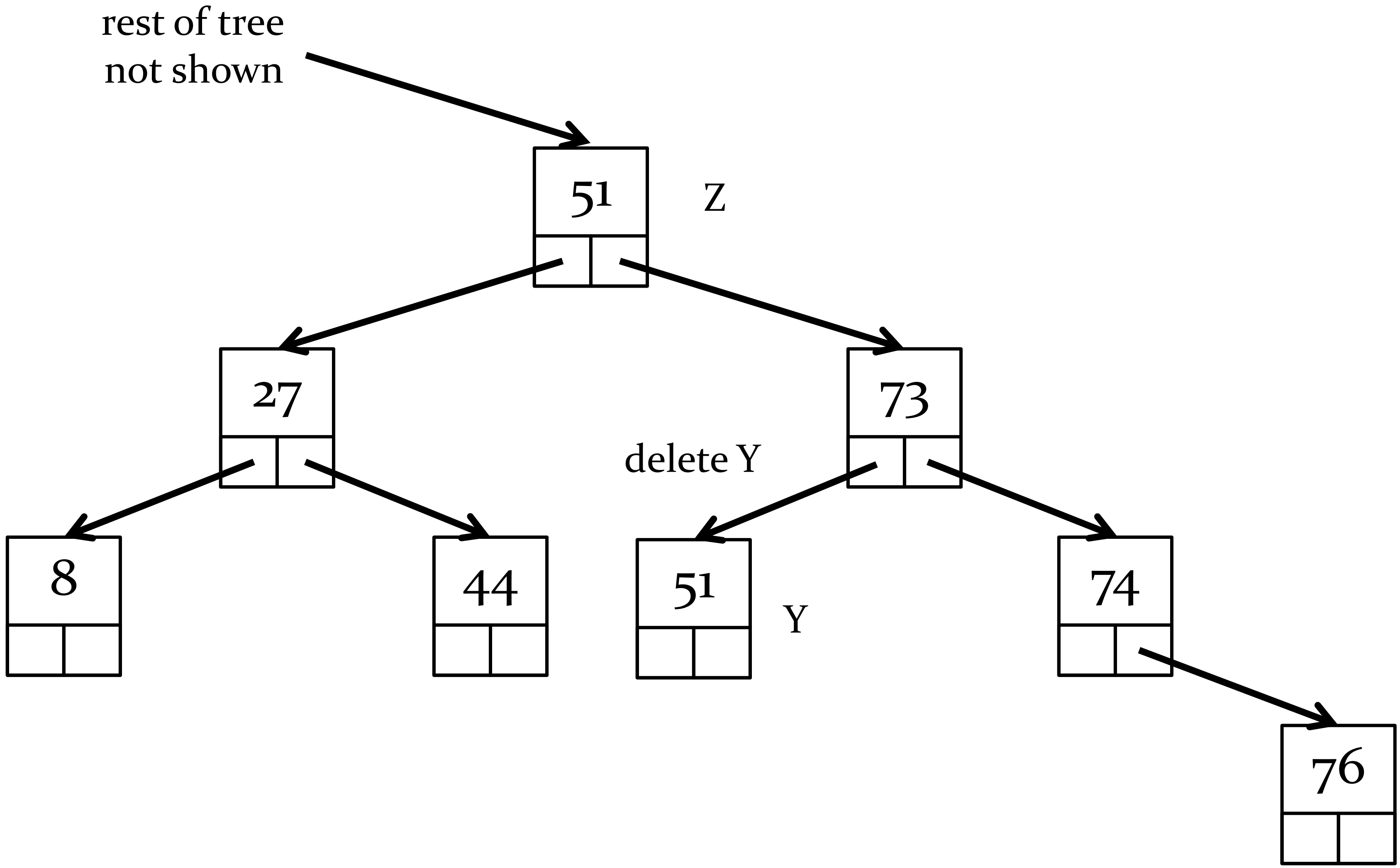


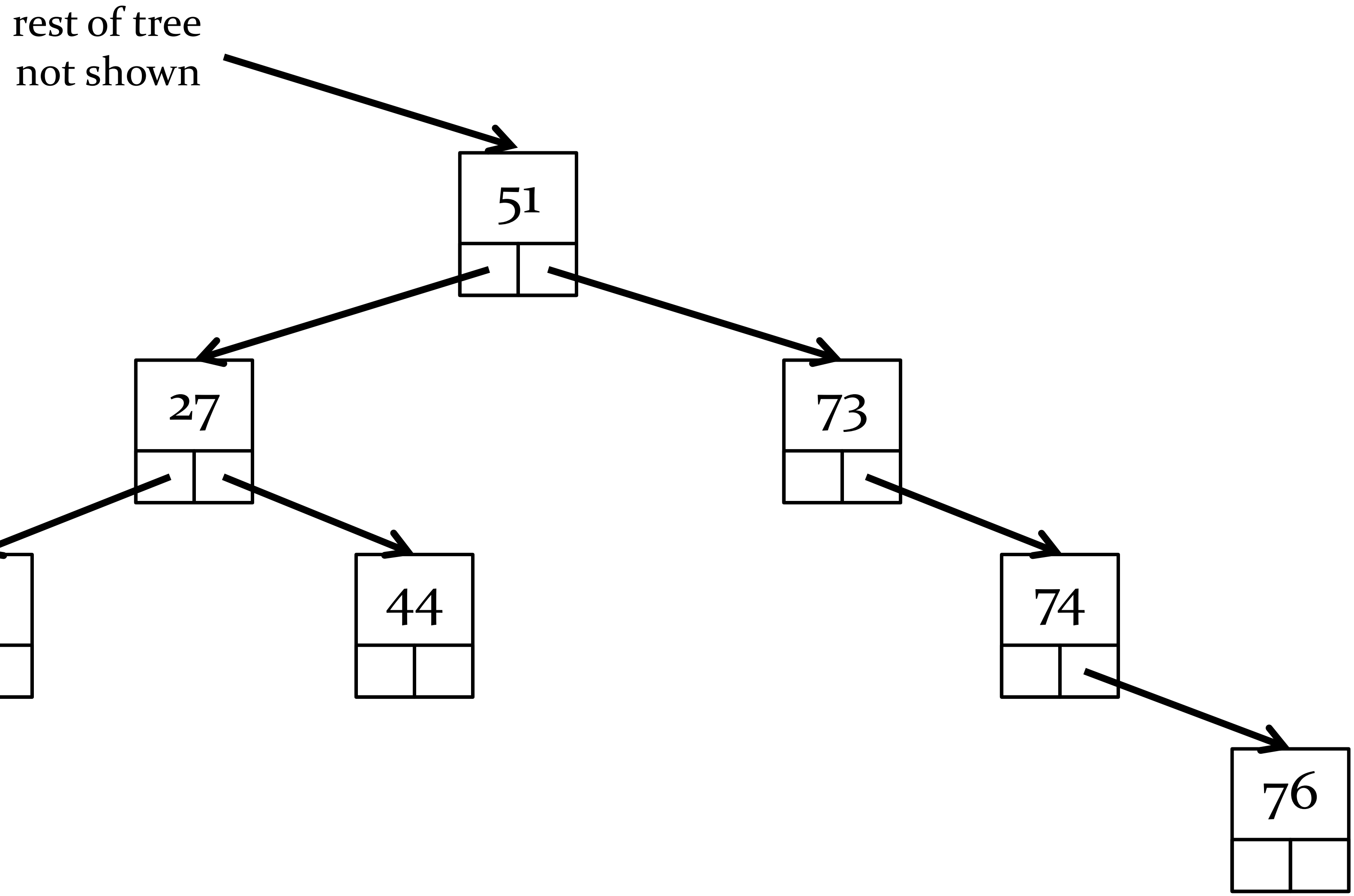
rest of tree
not shown
delete 50
50
27
73
8
44
51
74
76


rest of tree
not shown
50
Z
27
73
8
44
51
Y
74
76
inorder
successor
to Z



rest of tree
not shown
copy Y data to Z data
51
Z
27
73
8
44
51
Y
74
inorder
successor
to Z
76


rest of tree
not shown
51
Z
27
73
delete Y
8
44
51
Y
74
76



rest of tree
not shown
51
27
73
8
44
74
76

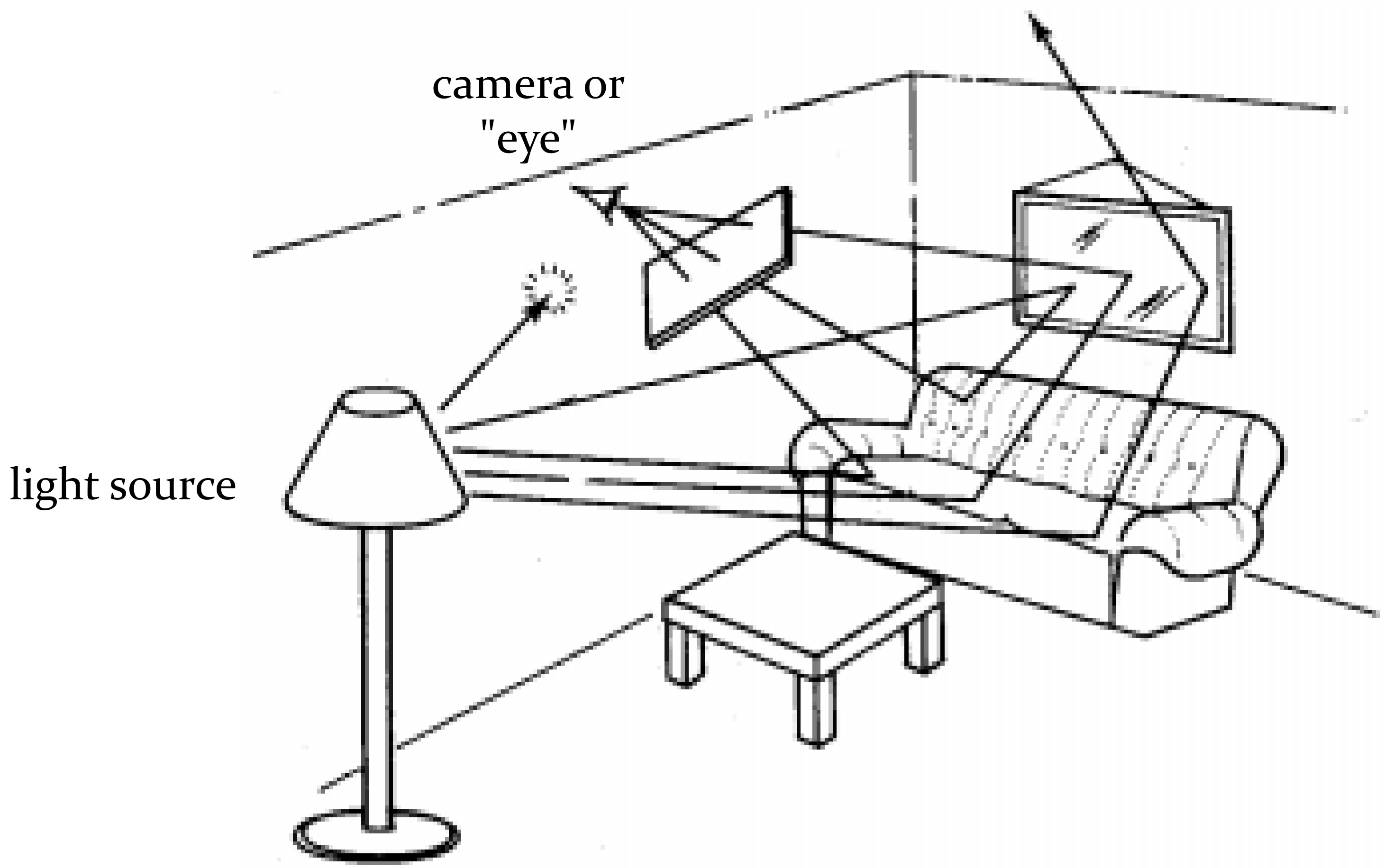
Recursion and Data Structures in Computer Graphics

Ray Tracing

Forward Ray Tracing

- imagine that you take a picture of a room using a camera
- exactly what is the camera sensing?
  - light reflected from the surfaces of objects into the camera lens

Forward Ray Tracing



Forward Ray Tracing

- forward ray tracing traces the paths of light from the light source to the camera to produce an image
- computationally infeasible because almost all of the possible paths of light miss the camera

Backward Ray Tracing

- backward ray tracing traces the paths of light from the camera out into the environment to produce an image
- computationally feasible because the process starts with a single* ray per screen pixel

Why Ray Tracing: Shadows

shadows with ~1000 light sources

Ray Tracing for the Movie 'Cars', P. Christensen et al

Ray Tracing: Reflections

Ray Tracing for the Movie 'Cars', P. Christensen et al

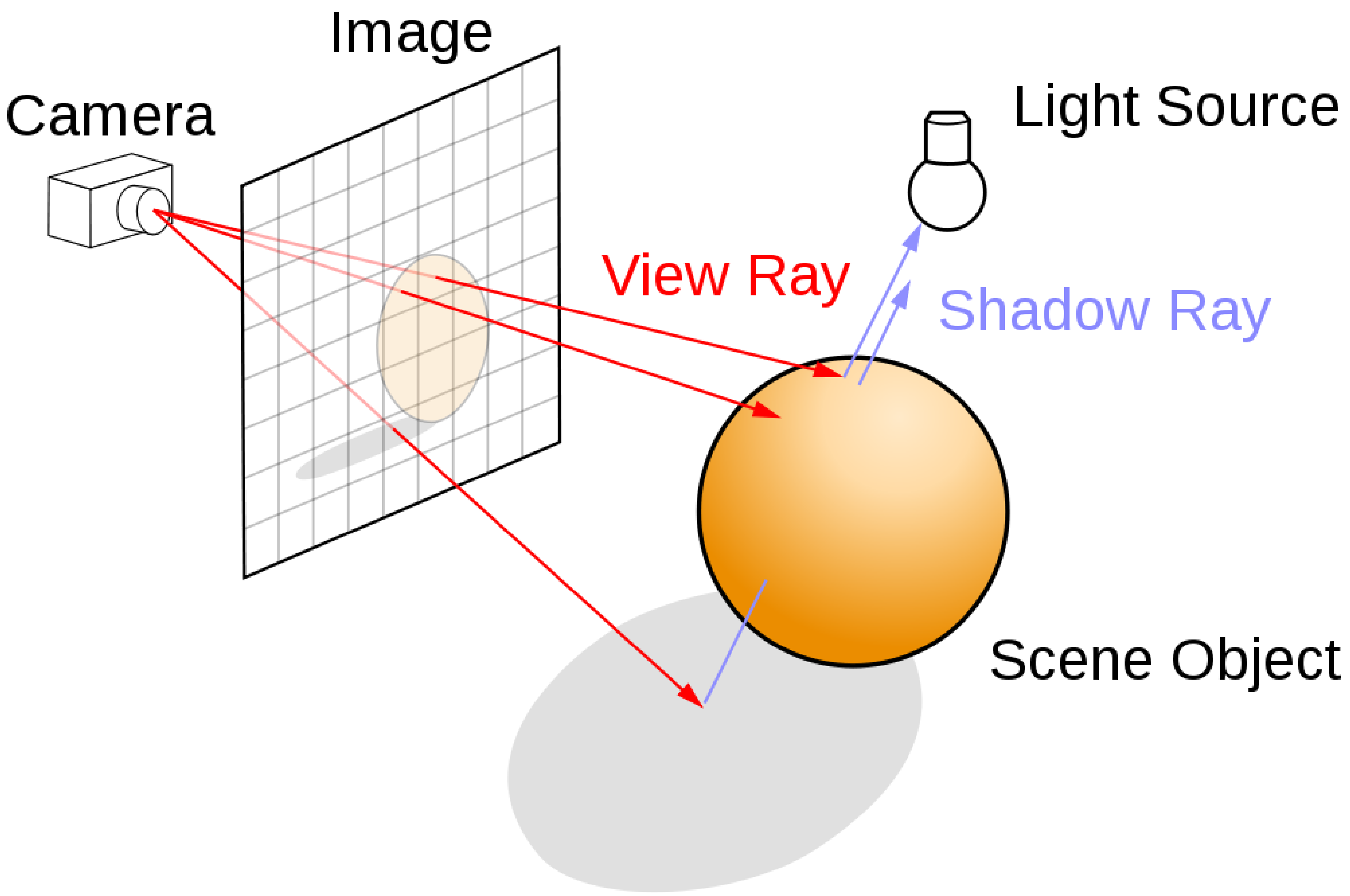
Ray Tracing: Reflections

Ray Tracing for the Movie 'Cars', P. Christensen et al

Comment on Previous Images

- most of the rendering in the previous images was not done using ray tracing
- ray tracing was only used on those parts of the image that would produce a noticeable difference

Backward Ray Tracing

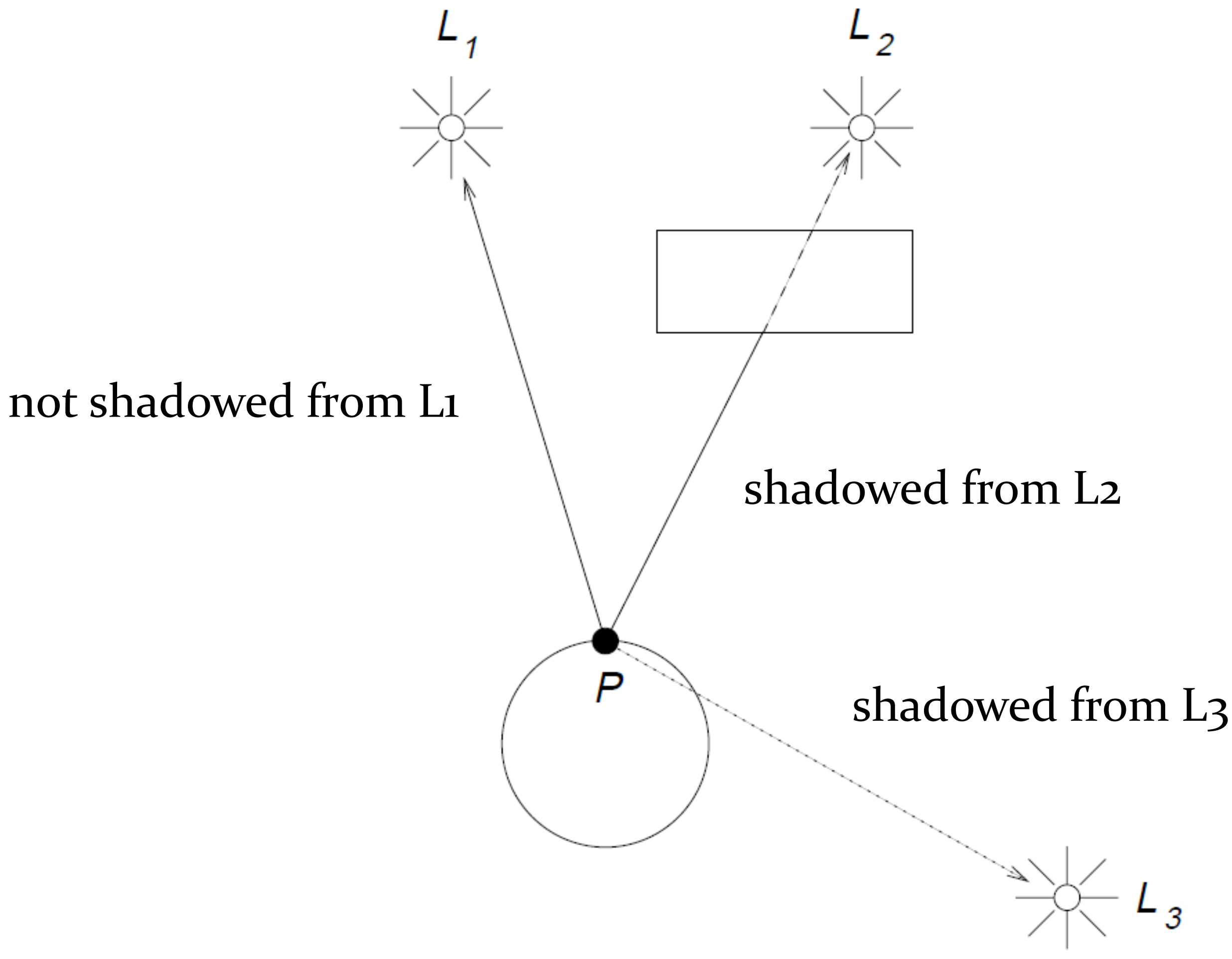


http://en.wikipedia.org/wiki/File:Ray_trace_diagram.svg

Shadows

- we can determine if a point is in shadow by tracing rays from the point to each light source
  - called shadow rays
- if a shadow ray hits an object before it reaches the light source then the point is in shadow

Shadows

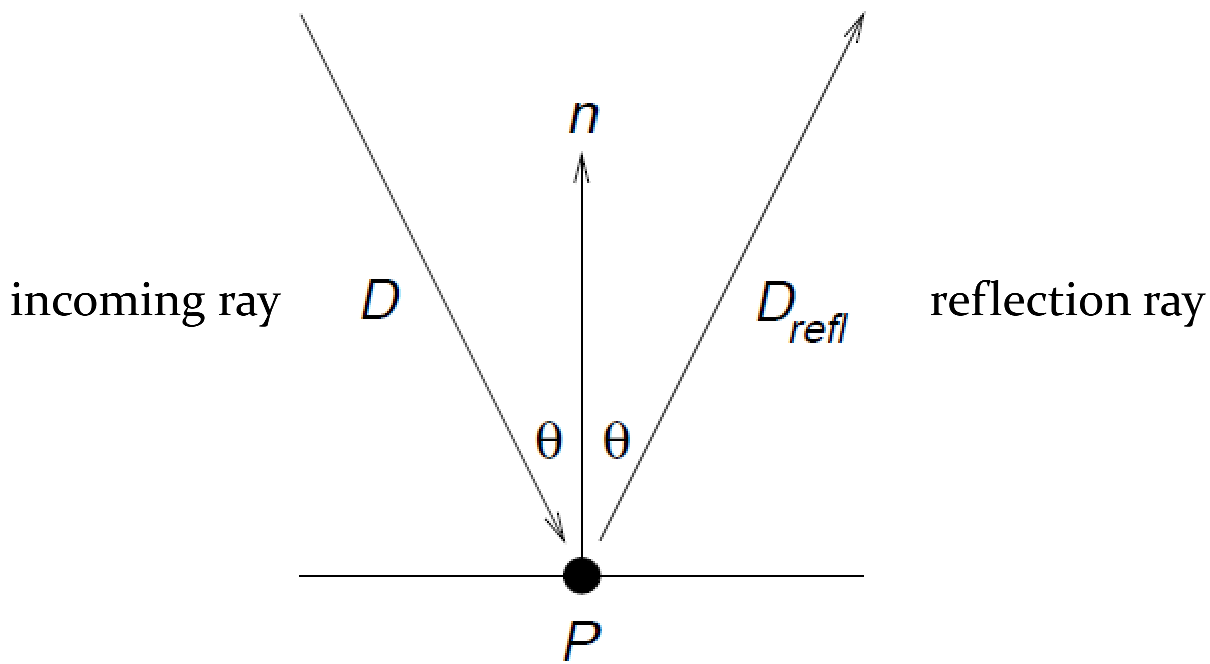


L 1
L 2
not shadowed from L1
shadowed from L2
P
shadowed from L3
L 3

Reflections

- if the ray hits a shiny object then we would like to know what reflection is seen at the hit point
- we can cast a new ray in the mirror reflection direction to determine the reflection

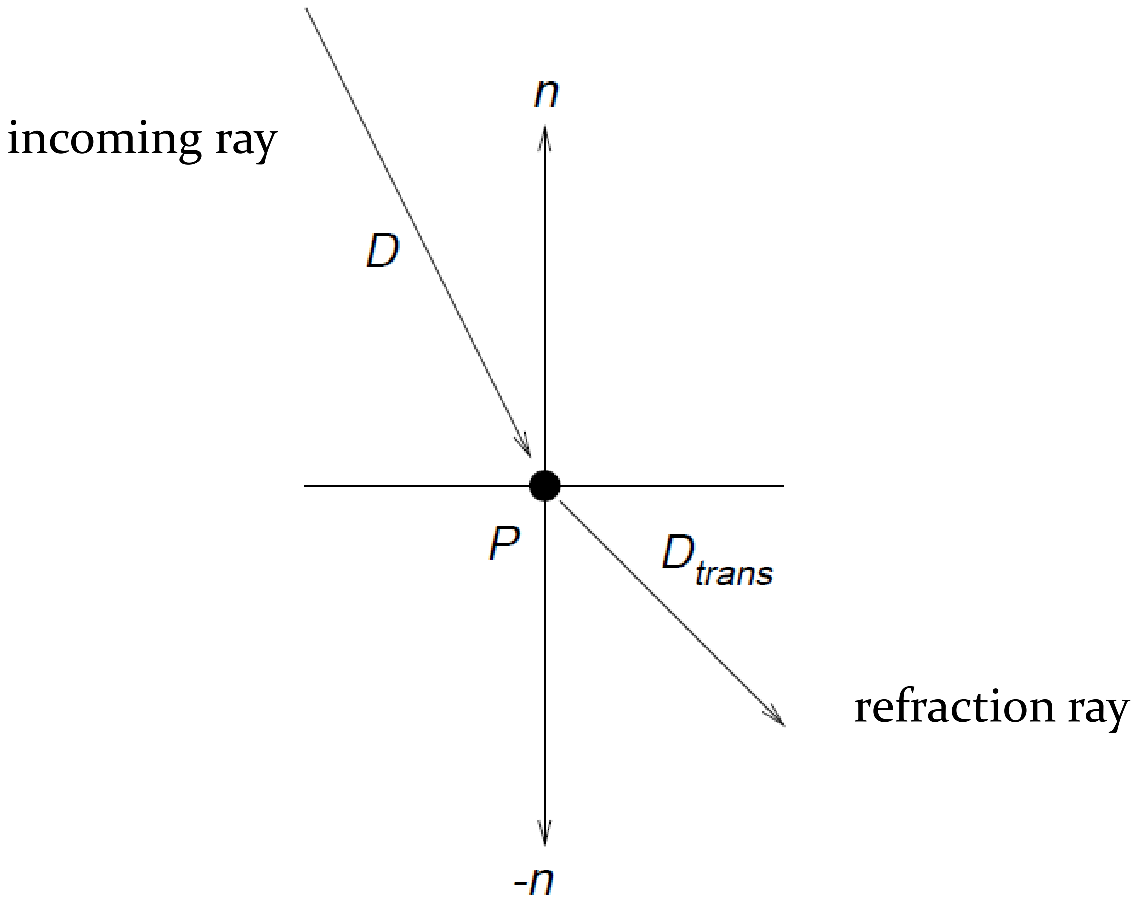
Reflections



Transparent Objects

- if the ray hits a transparent object then we would like to know what can be seen through the object
- we can cast a new ray in the refraction direction to determine what can be seen through the object

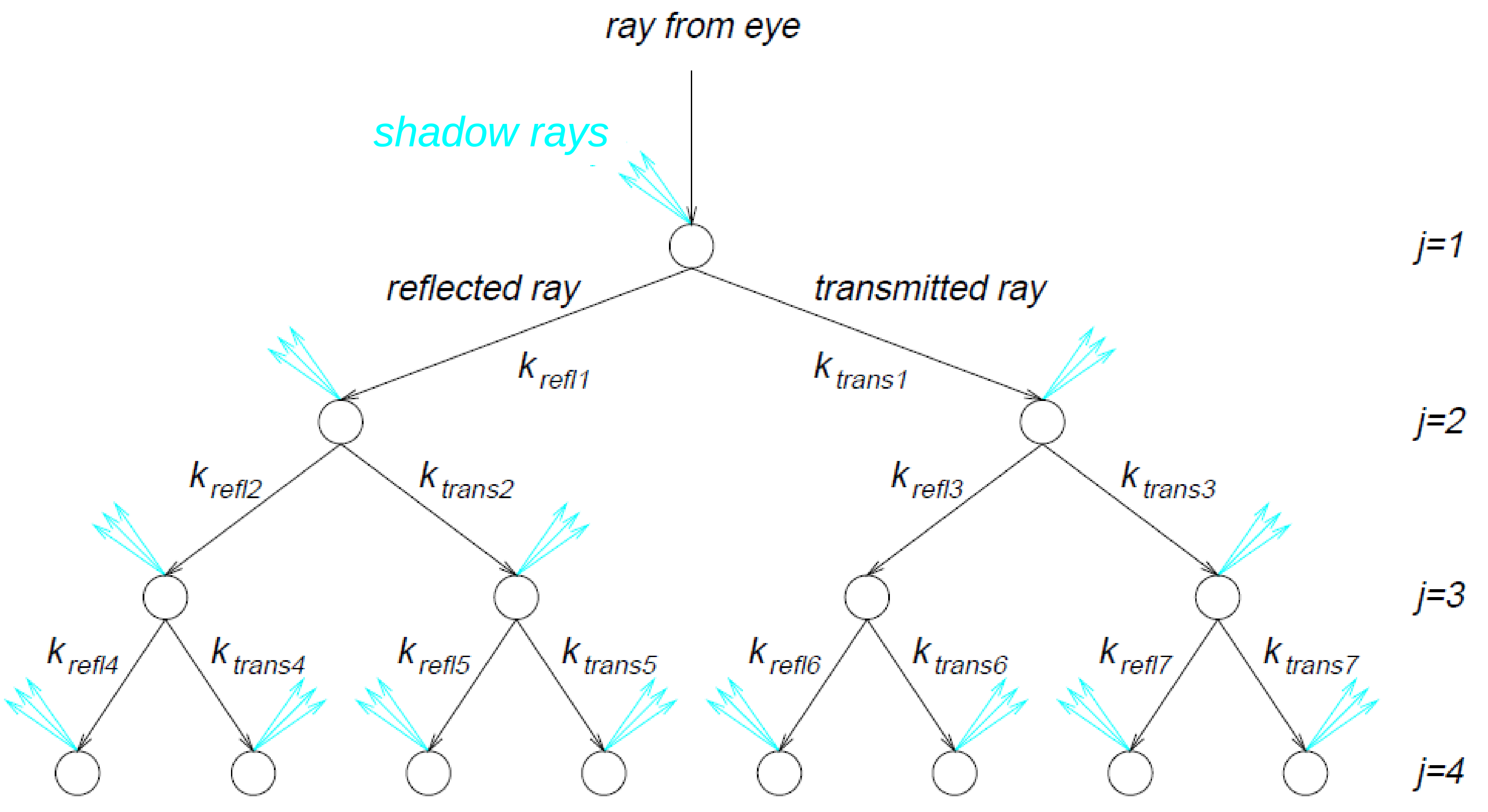
Transparent Objects



Recursion

- each reflected and refracted ray can be treated as a new emanating from a hit point
  - i.e., we recursively trace the reflected and refracted rays

Ray Tracing as a Binary Tree



Stopping the Recursion

- what are the base cases?
  - ray misses all objects
  - level of recursion exceeds a fixed value
  - other cases outside the scope of CSE1030

How Fast is Ray Tracing

- approaching real time for non-cinematic quality, e.g.,
  - Brigade 2 game engine
  - NVIDA OptiX
    - demos here if you have a high-end NVIDIA graphics card
- cinematic quality is much slower

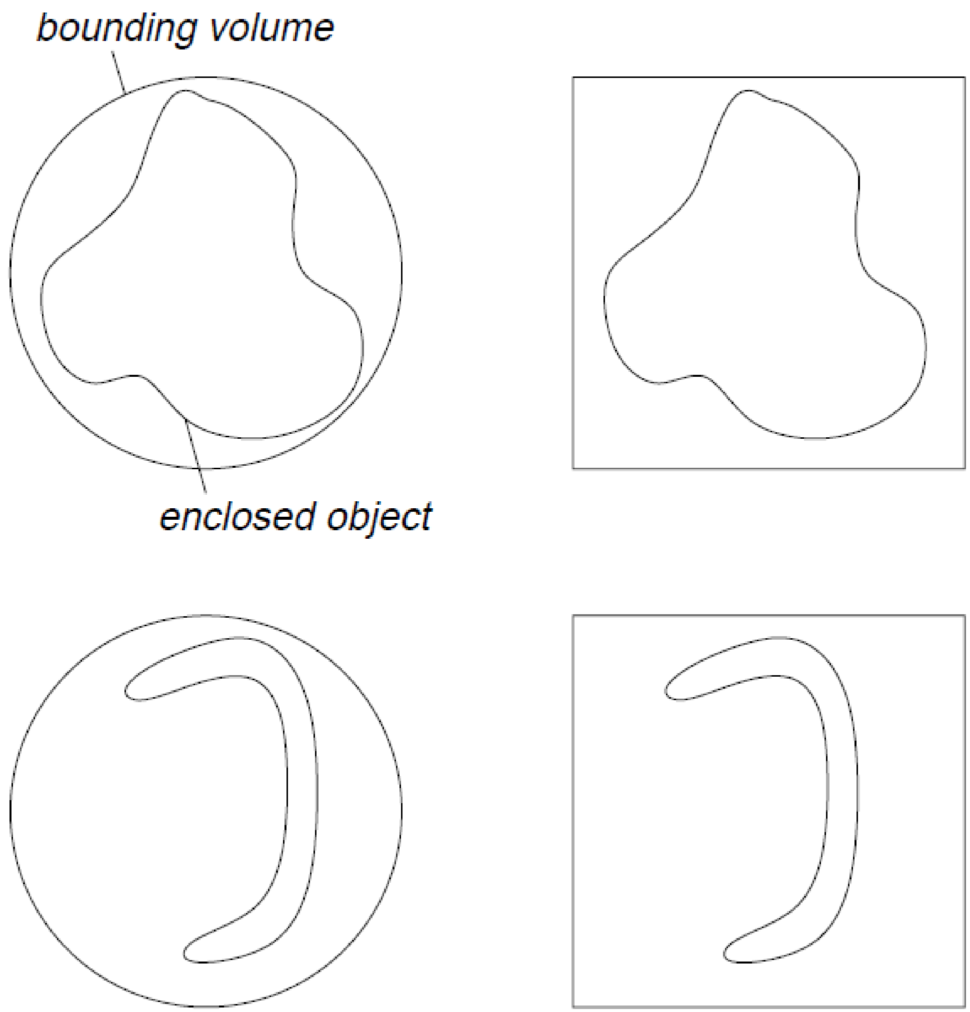
How Fast is Ray Tracing

- 678 million triangles
- rays
  - 111 million diffuse
  - 37 million specular
  - 26 million shadow
- 1.2 billion ray-triangle intersections
- 106 minutes on 2006 hardware

Bounding Volumes

- it is easy to compute the intersection of a ray with certain shapes, e.g.,
  - spheres and cubes
- it is hard or expensive to compute the intersection of a ray with arbitrary shapes
- idea
  - put complex shapes inside simple ones

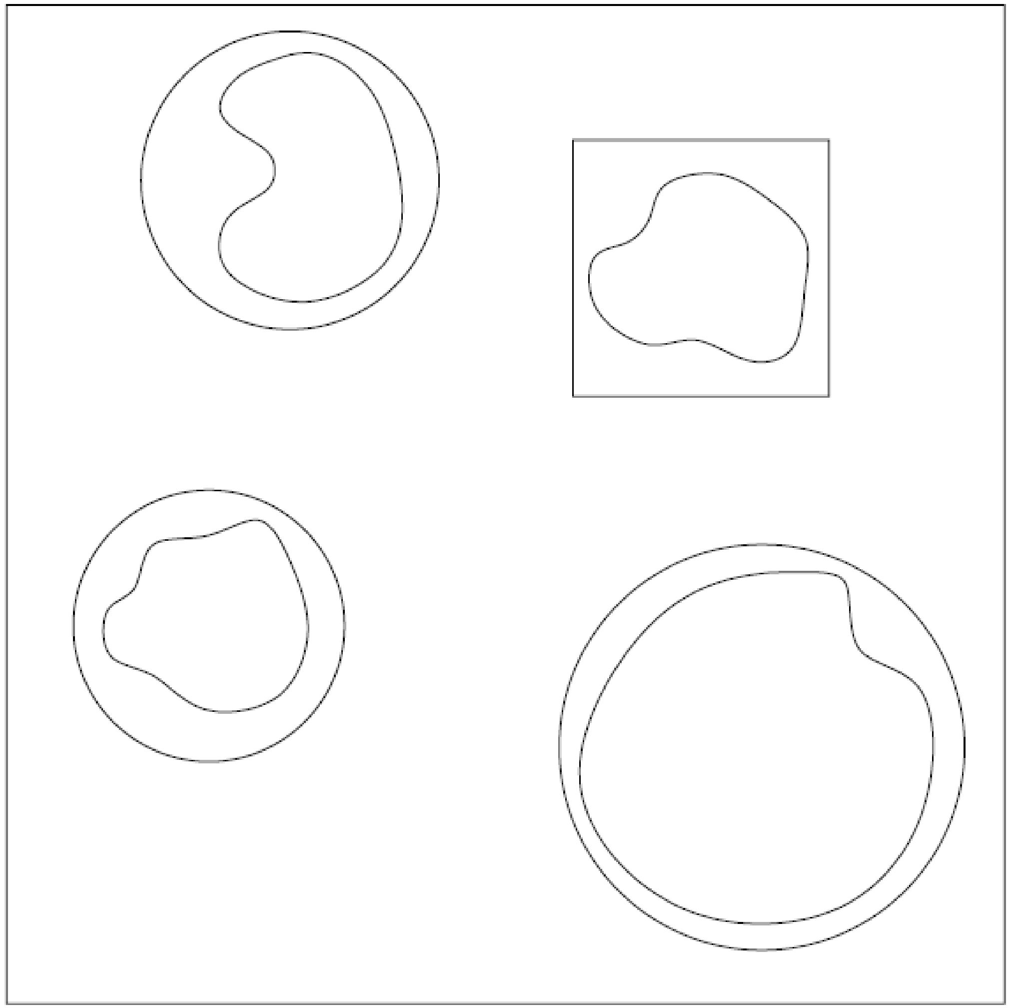
Bounding Volumes



Hierarchy of Bounding Volumes

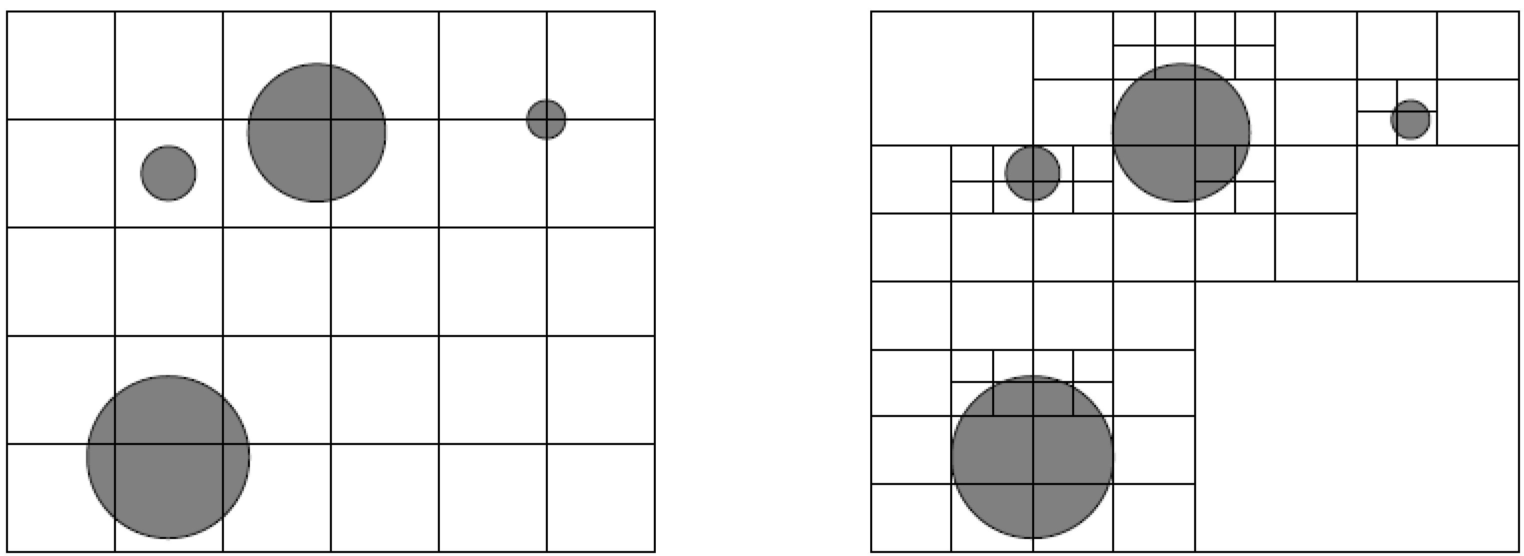
- why stop at putting complex shapes into bounding volumes?
- why not put bounding volumes inside bounding volumes?

Hierarchy of Bounding Volumes



Spatial Subdivision

- instead of putting objects inside volumes we can subdivide space



Quadtree Decomposition

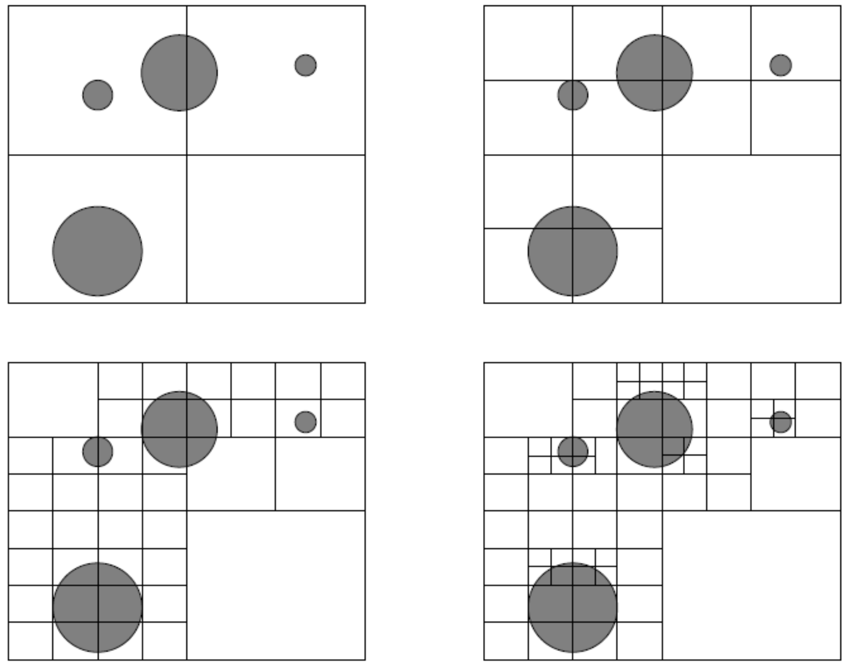


Figure 7.16: Quadtree decomposition of 2D space. Each quadrant of the world is recursively subdivided into subquadrants until the subquadrant meets some measure of simplicity. In this example, the recursive subdivision stops when then i) the subquadrant is occupied by zero objects or; ii) the object occupying the subquadrant takes up more than one-half the area of the subquadrant or; iii) the depth of recursion is four. A more common heuristic is to subdivide any quadrant that that is occupied by *n* or more objects.

Using a Quadtree in Ray Tracing

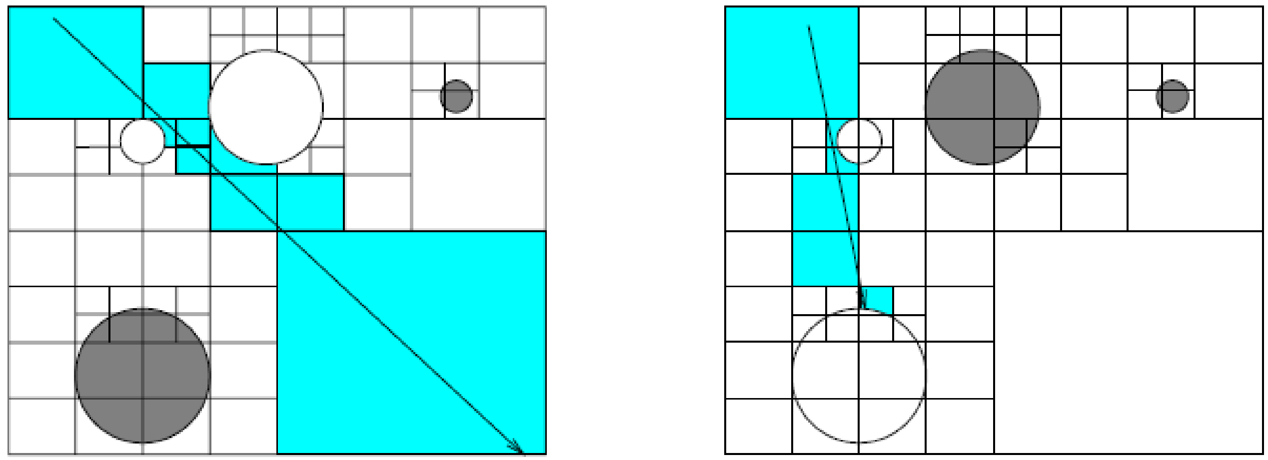


Figure 7.17: Using an octree to reduce the number of intersection calculations. On the left, nine voxels are examined and two objects are tested for an intersection with the ray. On the right, six voxels are examined and two objects are tested for an intersection with the ray. If an intersection is found, no more voxels need to be examined. This is because voxels are examined in the order that the ray passes through the world—the first intersection found must be the nearest hit point to the starting point of the ray.

Open Source Ray Tracers

- Art of Illusion
- POV-Ray
- YafaRay
- Manta
- several others