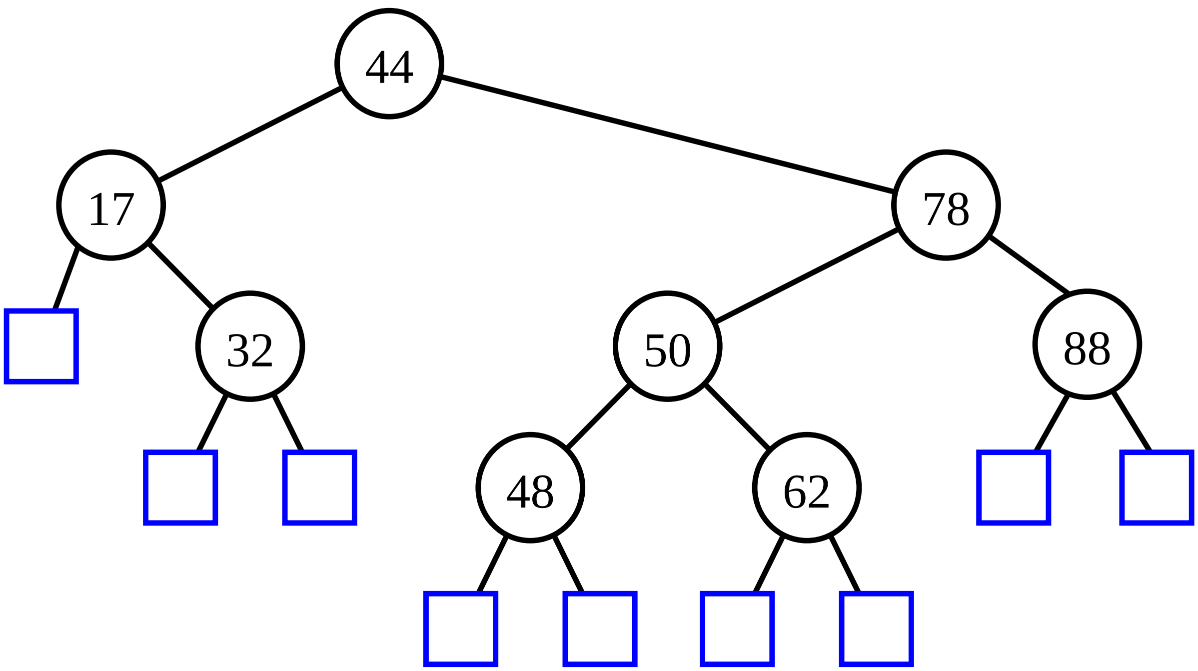
SEARCHING

- the dictionary ADT
- binary search
- binary search trees

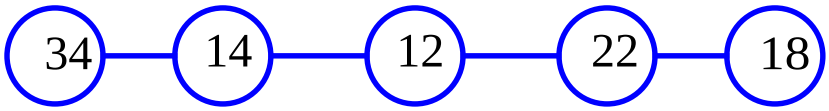


The Dictionary ADT

- a dictionary is an abstract model of a database
- like a priority queue, a dictionary stores key-element pairs
- the main operation supported by a dictionary is searching by key
- simple container methods:
  - size()
  - isEmpty()
  - elements()
- query methods:
  - findElement(k)
  - findAllElements(k)
- update methods:
  - insertItem(k, e)
  - removeElement(k)
  - removeAllElements(k)
- special element
  - NO_SUCH_KEY, returned by an unsuccessful search

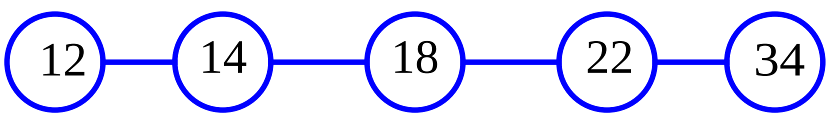
Implementing a Dictionary with a Sequence

- ***unordered sequence***



  - searching and removing takes O(n) time
  - inserting takes O(1) time
  - applications to log files (frequent insertions, rare searches and removals)

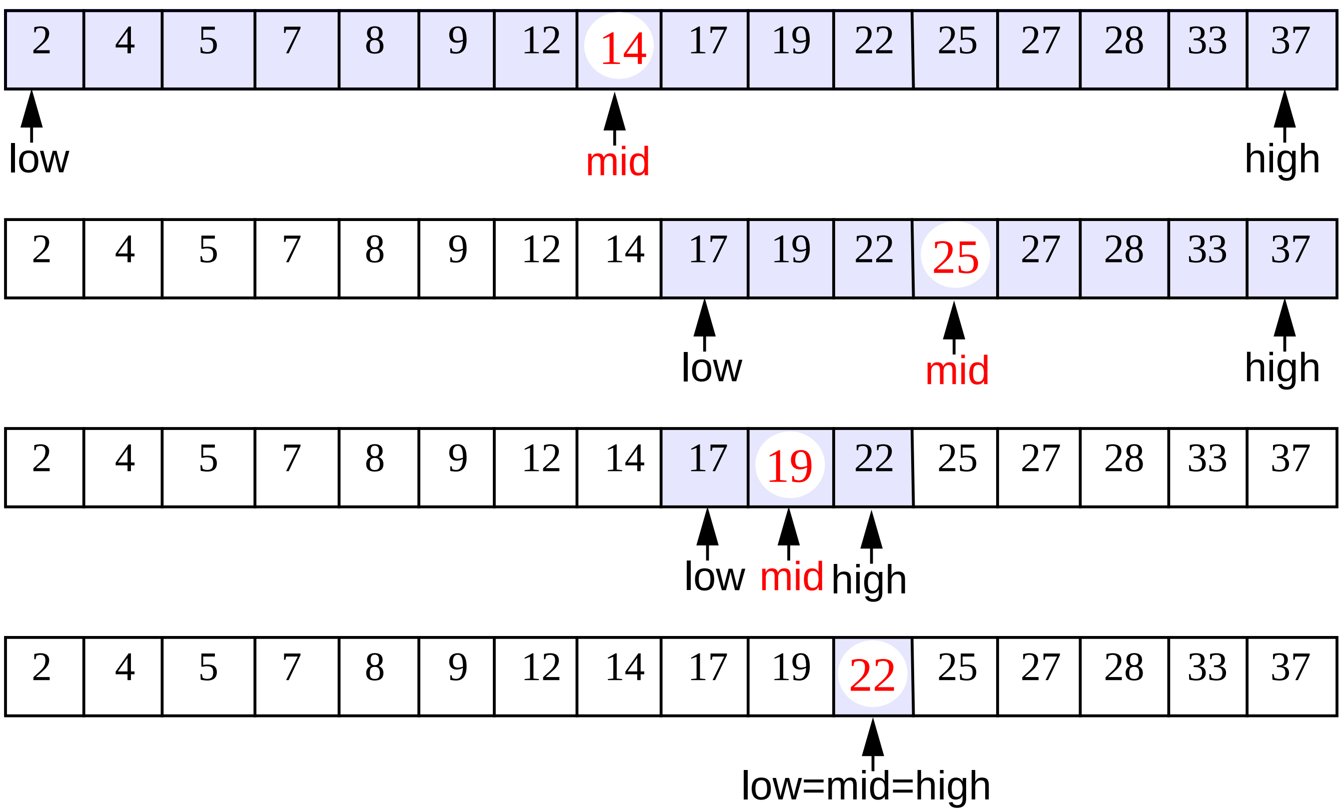
- ***array-based ordered sequence*** (assumes keys can be ordered)



  - searching takes O(log n) time (***binary search***)
  - inserting and removing takes O(n) time
  - application to look-up tables (frequent searches, rare insertions and removals)

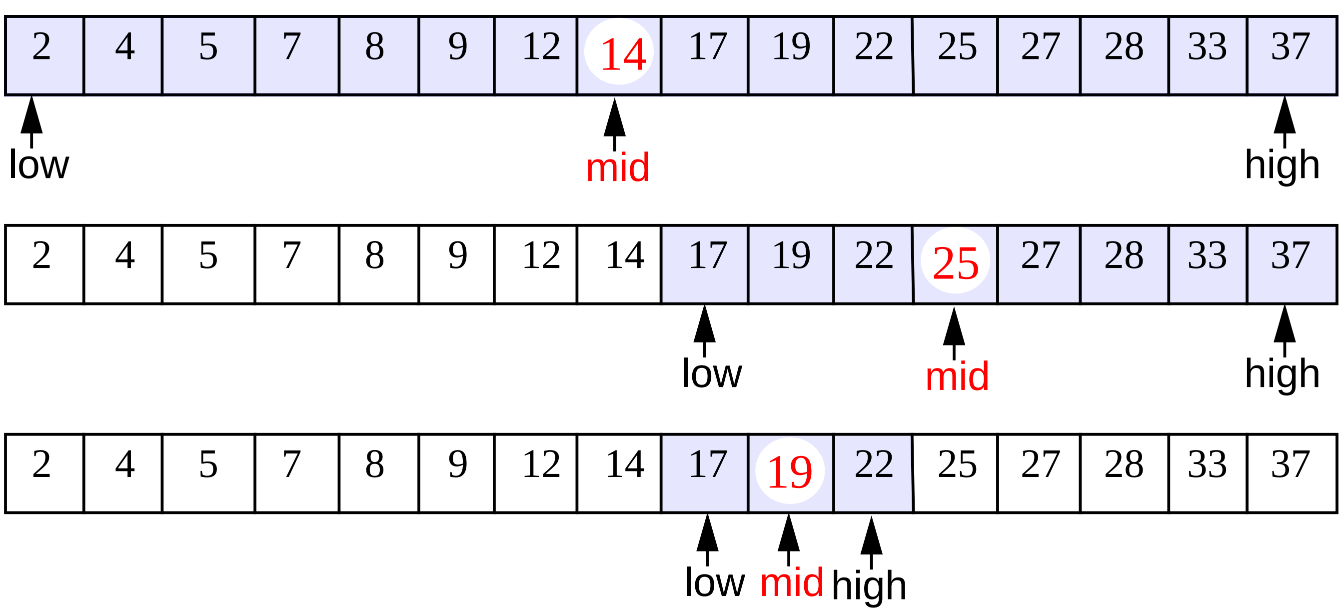
Binary Search

- narrow down the search range in stages
- “high-low” game
- findElement(22)



Pseudocode for Binary Search

```
Algorithm BinarySearch(S, k, low, high)
if low > high then
   return NO_SUCH_KEY
else
   mid ← (low+high) / 2
   if k = key(mid) then
      return key(mid)
   else if k < key(mid) then
      return BinarySearch(S, k, low, mid–1)
   else
      return BinarySearch(S, k, mid+1, high)
```



Running Time of Binary Search

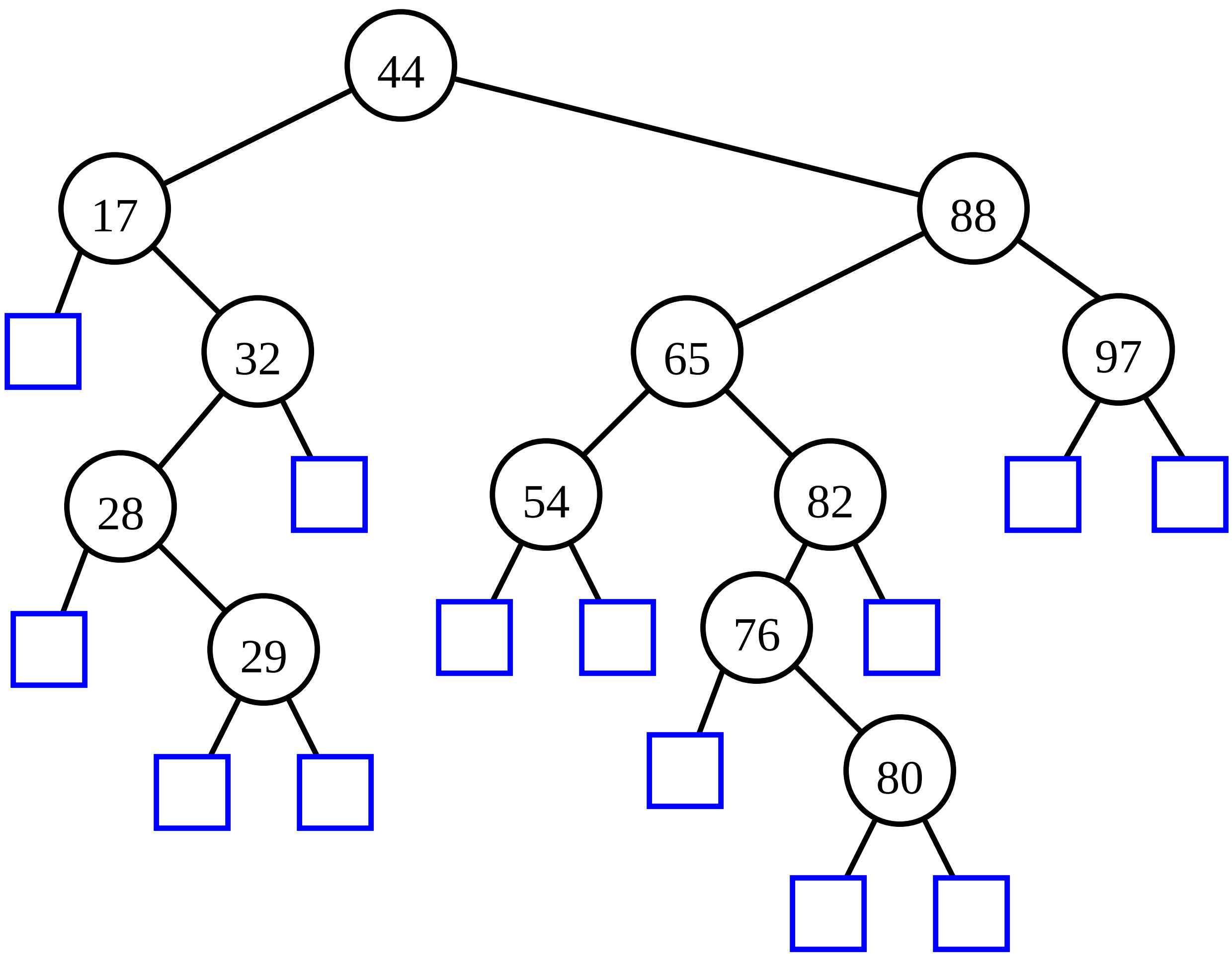
- The range of candidate items to be searched is ***halved after each comarison***

comparison	**search range**
0	n
1	$n/2$
2	$n/4$
...	...
2^i	$n/2^i$
$\log_2 n$	1

- In the array-based implementation, access by rank takes O(1) time, thus binary search runs in **O(log *n*)** time

Binary Search Trees

- A binary search tree is a binary tree T such that
  - each internal node stores an item (k, e) of a dictionary.
  - keys stored at nodes in the left subtree of v are less than or equal to k.
  - keys stored at nodes in the right subtree of v are greater than or equal to k.
  - kxternal nodes do not hold elements but serve as place holders.



Search

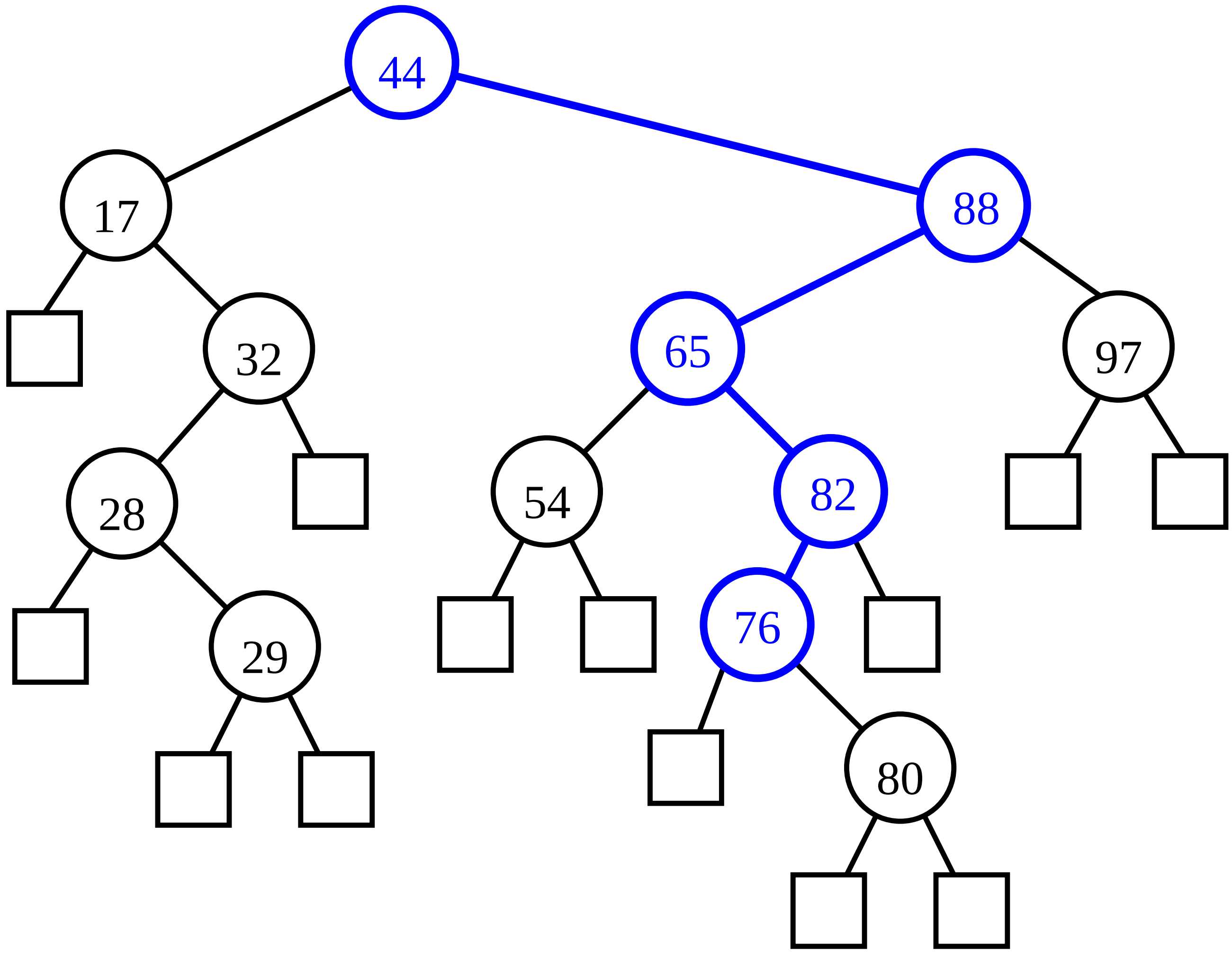
- A binary search tree T is a ***decision tree***, where the question asked at an internal node v is whether the search key k is less than, equal to, or greater than the key stored at v.

- Pseudocode:

Algorithm TreeSearch(k, v):
   Input: A search key k and a node v of a binary search tree T.
   Ouput: A node w of the subtree $T(v)$ of T rooted at v, such that either w is an internal node storing key k or w is the external node encountered in the inorder traversal of $T(v)$ after all the inter nal nodes with keys smaller than k and before all the internal nodes with keys greater than k.
   if v is an external node **then**
      return v
   if k = key(v) **then**
      return v
   else if k < key(v) **then**
      return TreeSearch(k, T.leftChild(v))
   else
      { k > key(v) }
      return TreeSearch(k, T.rightChild(v))

Search Example I

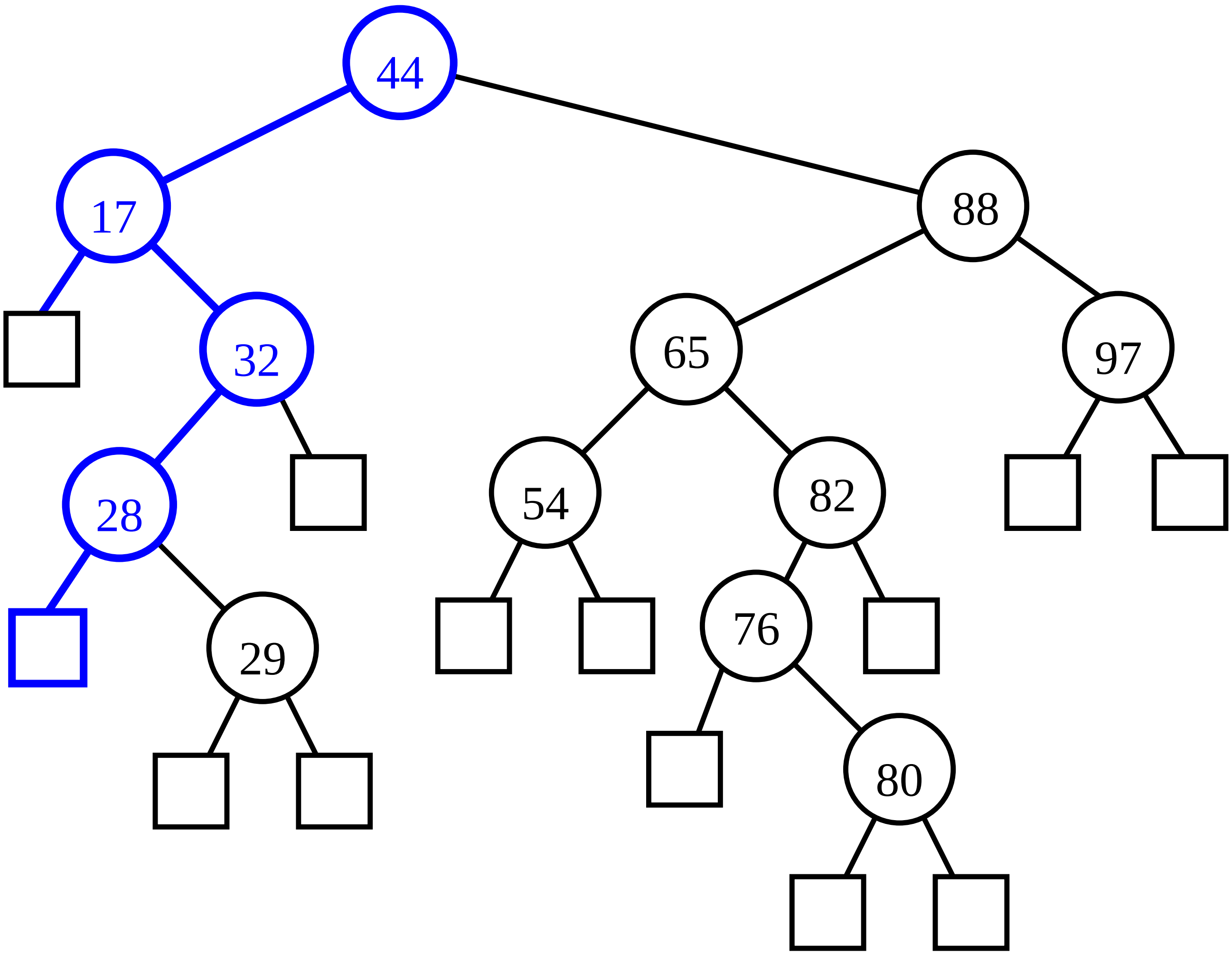
- Successful findElement(76)



- A successful search traverses a path starting at the root and ending at an internal node
- How about findAllelements(k)?

Search Example II

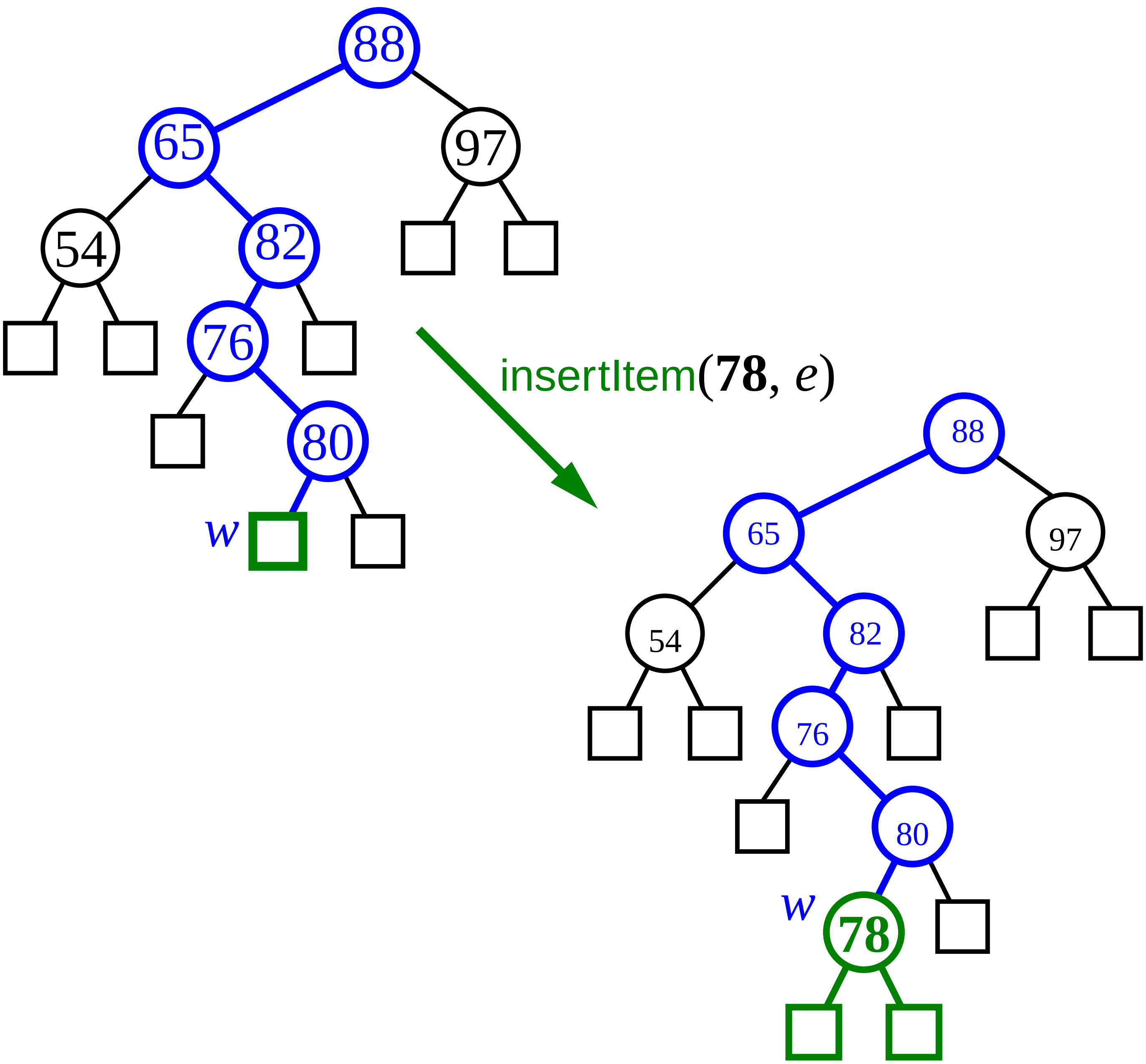
- Unsuccessful findElement(25)



- An unsuccessful search traverses a path starting at the root and ending at an external node

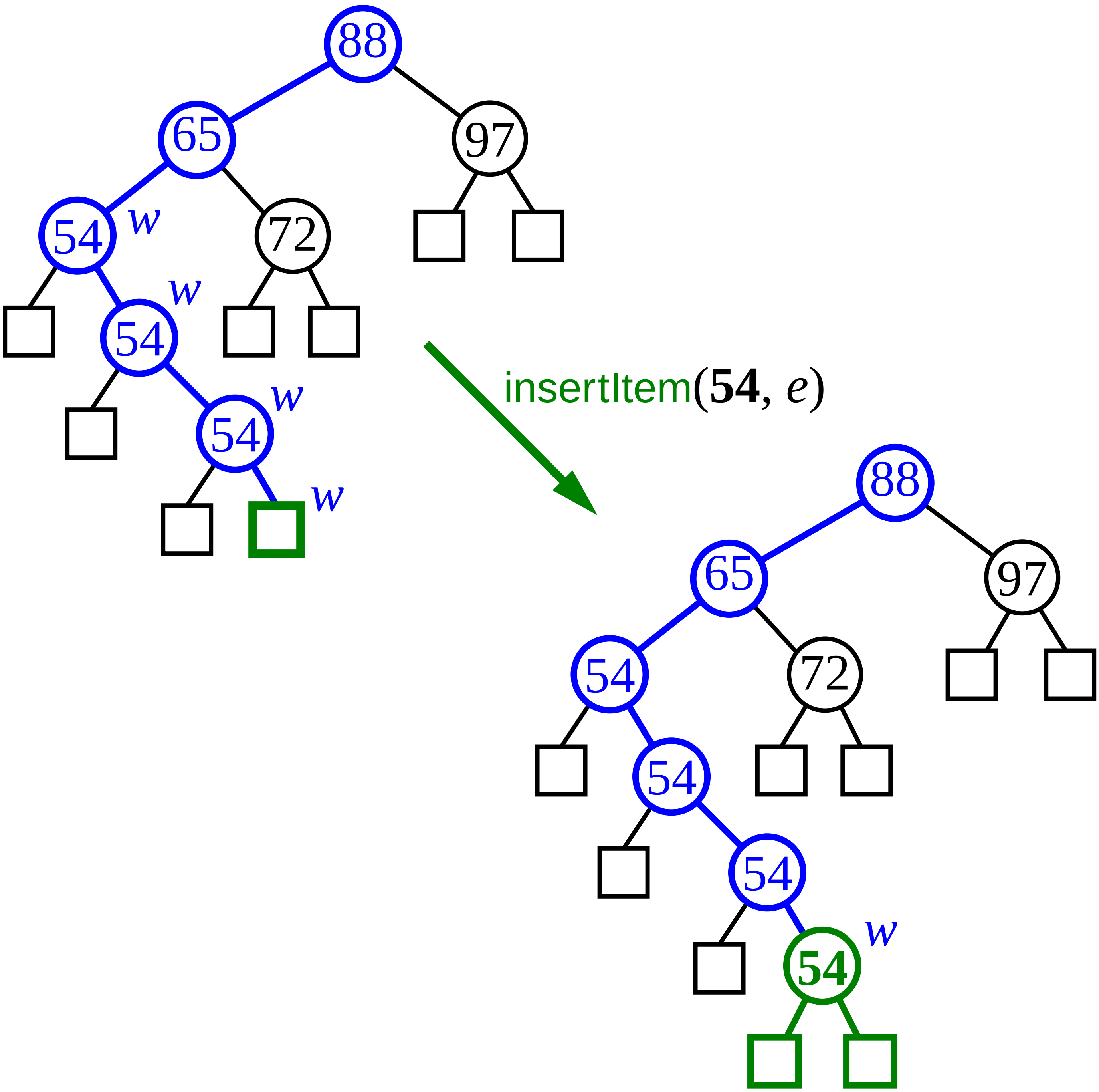
Insertion

- To perform insertItem(k, e), let w be the node returned by TreeSearch(k, T.root())
- If w is external, we know that k is not stored in T. We call expandExternal(w) on T and store (k, e) in w



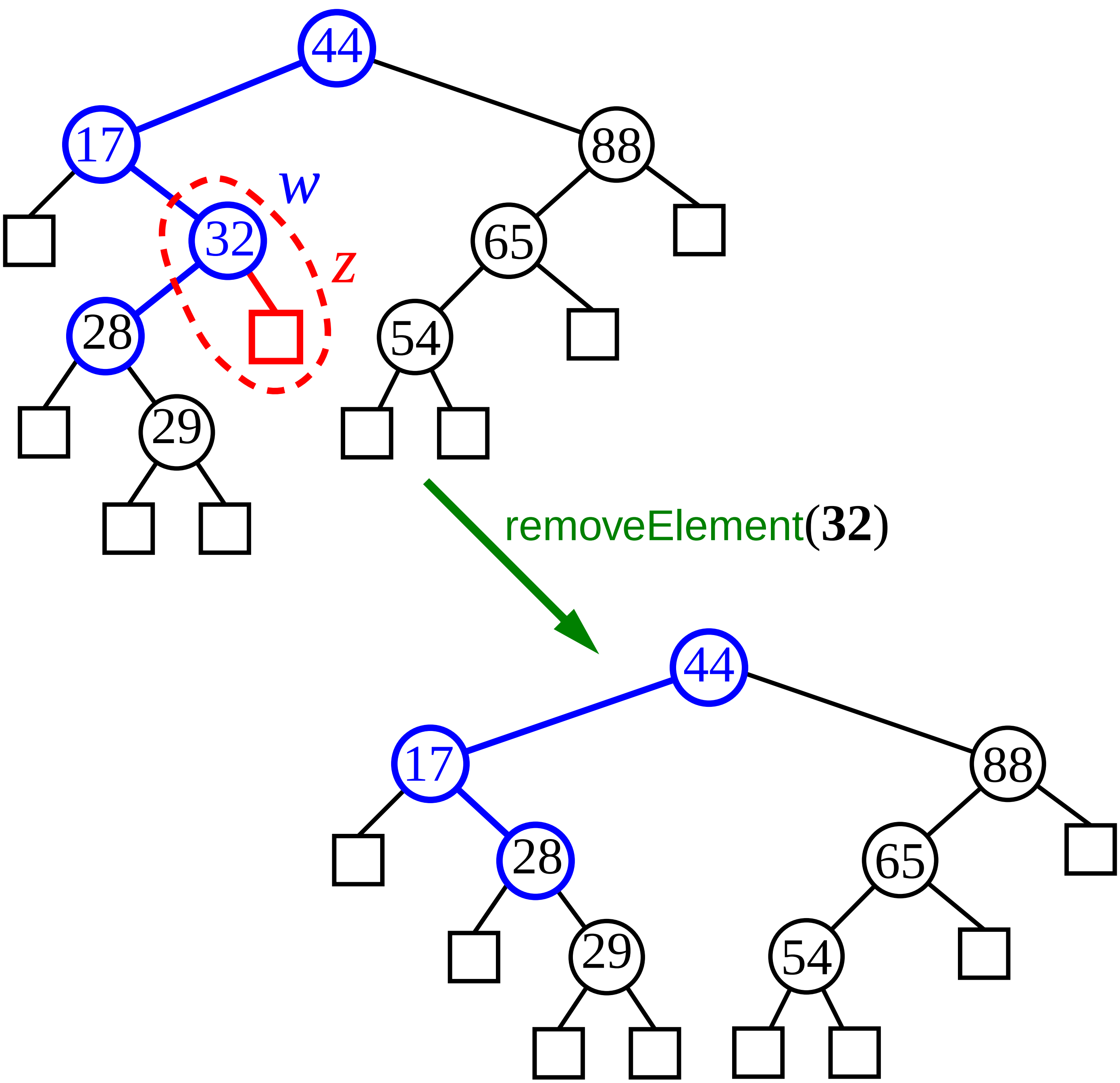
Insertion II

- If *w* is internal, we know another item with key *k* is stored at *w*. We call the algorithm recursively starting at *T*.rightChild(*w*) or *T*.leftChild(*w*)



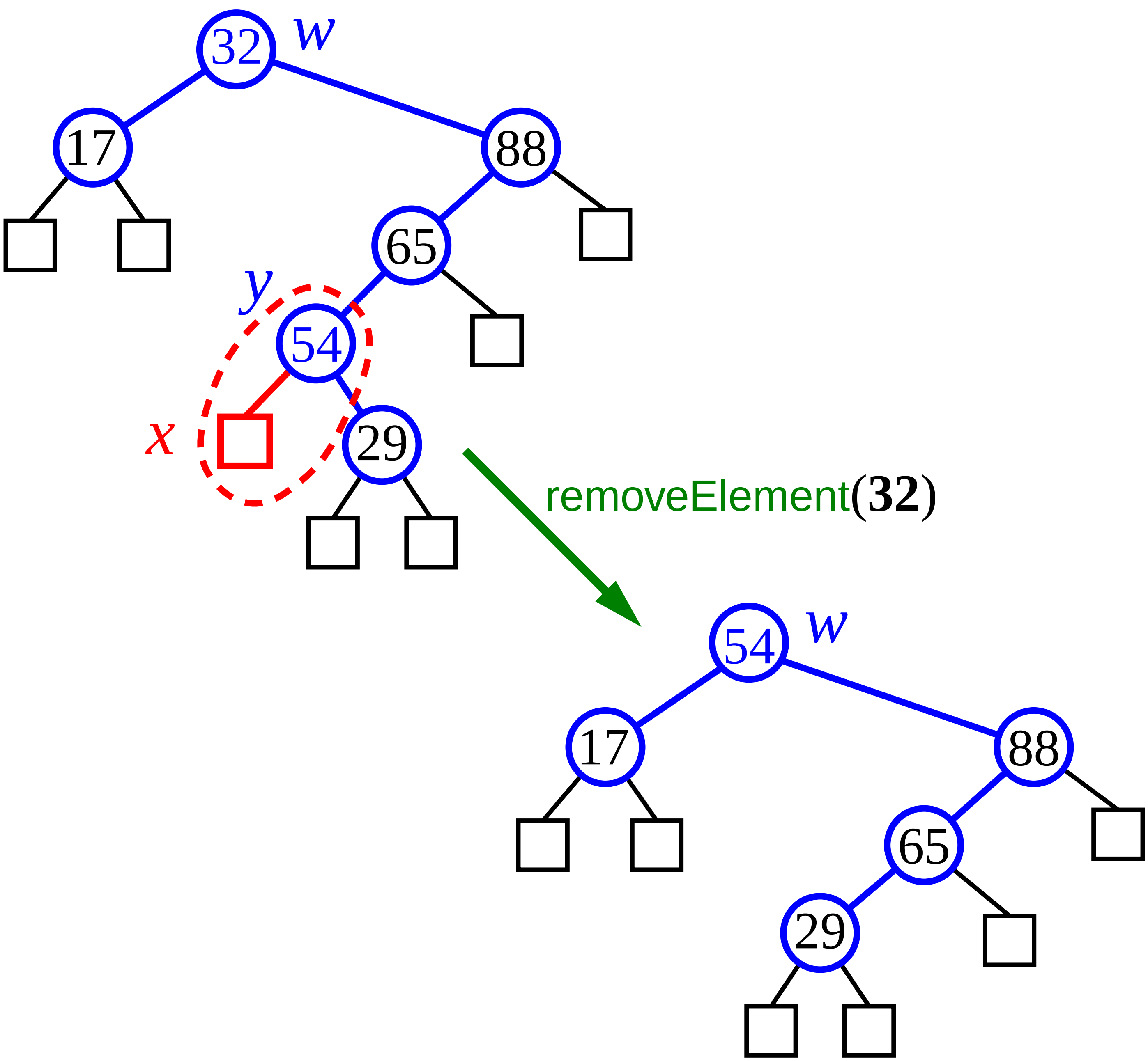
Removal I

- We locate the node *w* where the key is stored with algorithm TreeSearch
- If *w* ***has an external child*** *z*, we remove *w* and *z* with removeAboveExternal(*z*)



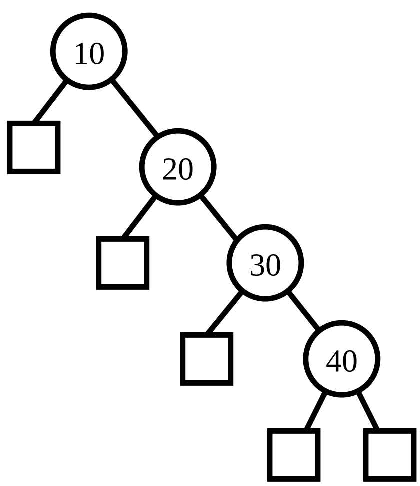
Removal II

- If *w* ***has an no external children***:
  - find the internal node *y* following *w* in inorder
  - move the item at *y* into *w*
  - perform removeAboveExternal(*x*), where *x* is the left child of *y* (guaranteed to be external)



Time Complexity

- A search, insertion, or removal, visits the nodes along a ***root-to leaf path***, plus possibly the ***siblings*** of such nodes
- Time O(1) is spent at each node
- The running time of each operation is O(*h*), where *h* is the height of the tree
- The height of binary serch tree is in *n* in the worst case, where a binary search tree looks like a sorted sequence



- To achive good running time, we need to keep the tree ***balanced***, i.e., with O(log *n*) height
- Various balancing schemes will be explored in the next lectures