Lecture 3
Recap of basic data structures, binary search, insertion/selection sort

CS 161 Design and Analysis of Algorithms

Ioannis Panageas

Outline of these notes

- Review of basic data structures
- Searching in a sorted array/binary search: the algorithm, analysis, proof of optimality
- Sorting, part 1: insertion sort, selection sort

Basic Data structures

Prerequisite material. Review [GT Chapters 2–4, 6] as necessary)

- Arrays, dynamic arrays
- Linked lists
- Stacks, queues
- Dictionaries, hash tables
- Binary trees

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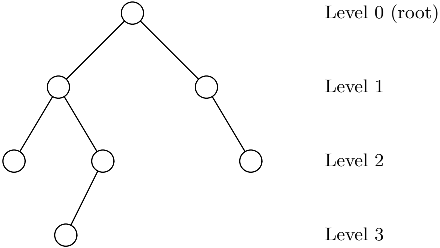
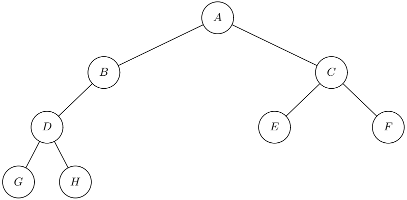


The depth of a binary tree is the maximum of the levels of all its leaves.

Traversing binary trees



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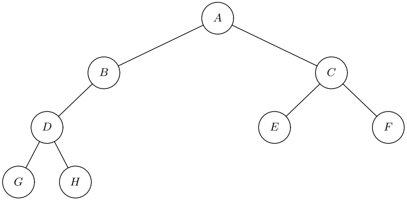

- Preorder: root, left subtree (in preorder), right subtree (in preorder): *ABDGHCEF*

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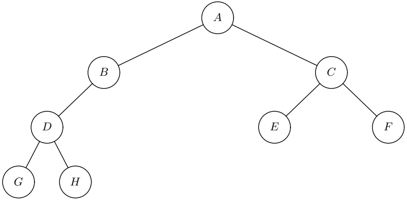

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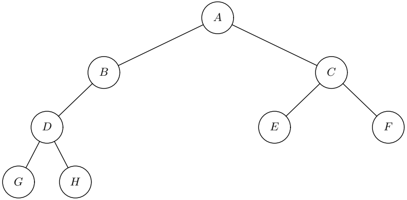

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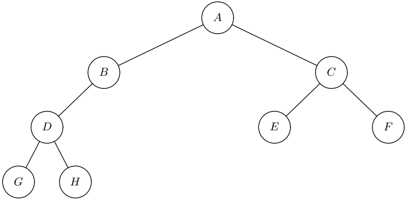

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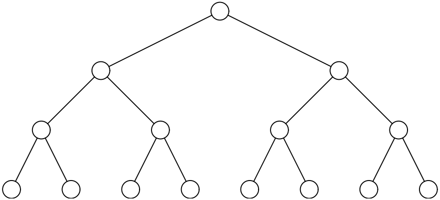
- Breadth-first order (level order): level 0 left-to-right, then level 1 left-to-right, . . . : *ABCDEFGH*

Facts about binary trees



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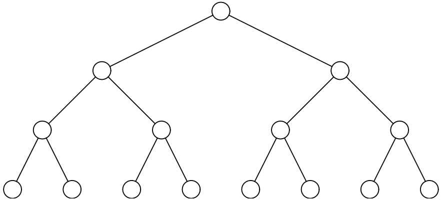

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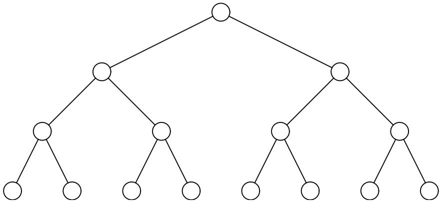

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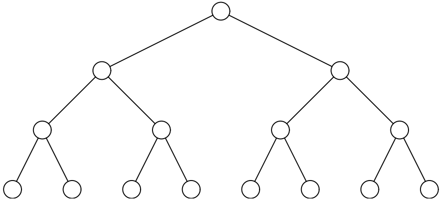

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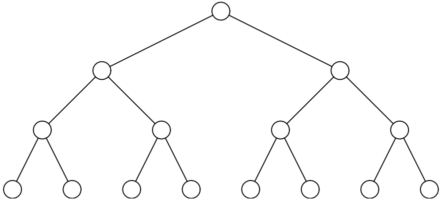

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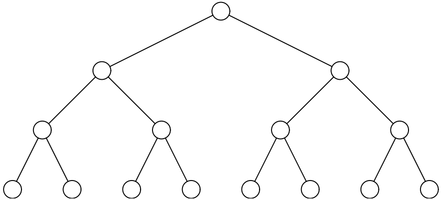

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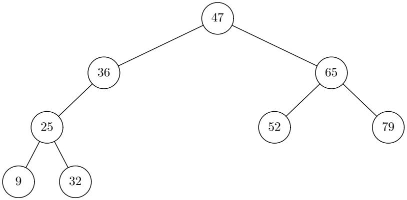

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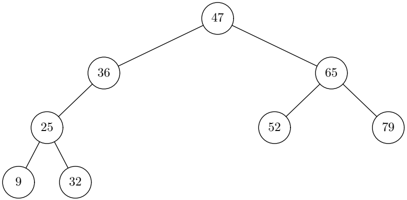

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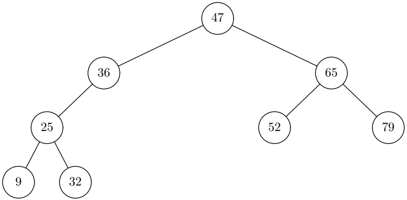

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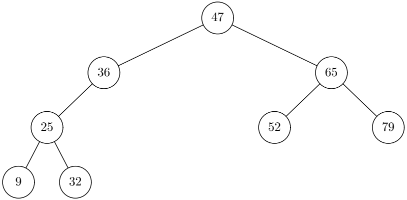

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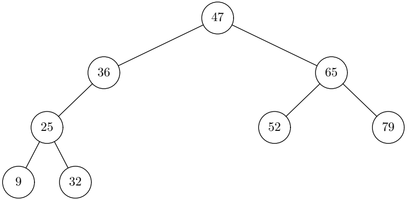

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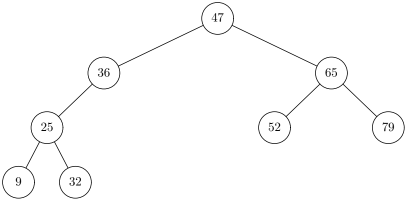

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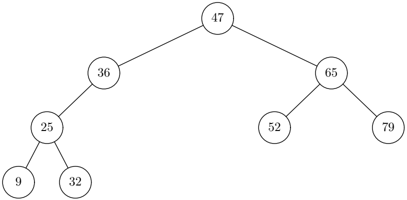

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- [GT] Chapters 3–4 for details

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  We will focus on the first variant.

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- Several variants of the problem, for example...
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  2. Find the largest i such that $A[i] \leq x$ (with a reasonable convention if $x < A[0]$).

  We will focus on the first variant.
- We will show that binary search is an optimal algorithm for solving this problem.

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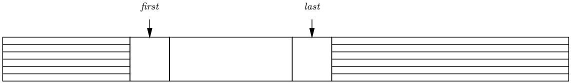
```
def binarySearch(A,x,first,last)
if first > last:
  return (-1)
else:
  mid = ⌊(first+last)/2⌋
  if x == A[mid]:
    return mid
  else if x < A[mid]:
    return binarySearch(A,x,first,mid-1)
  else:
    return binarySearch(A,x,mid+1,last)

binarySearch(A,x,0,n-1)
```

Correctness of Binary Search



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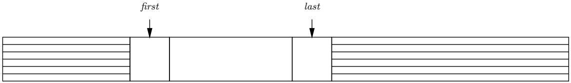

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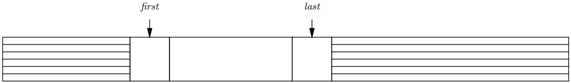

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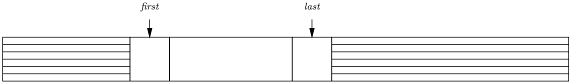

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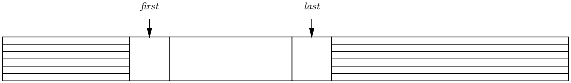
2. On each recursive call, the difference *last* − *first* gets strictly smaller.



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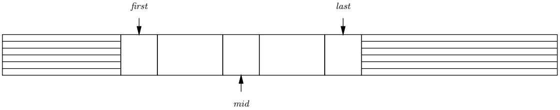

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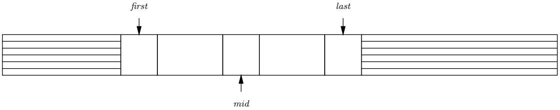

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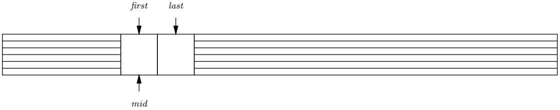

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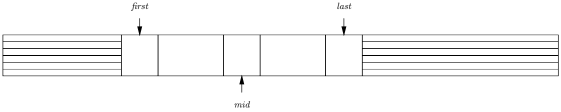

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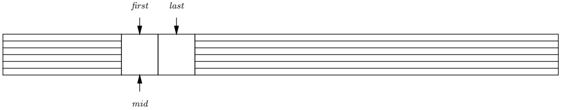

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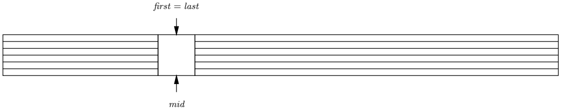

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  2. Gives us a way to compare binary search against other algorithms that solve the same problem: searching for an item in an array by comparing the item against array entries.

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- So binary search does $\lfloor \lg n \rfloor + 1$ 3-way comparisons on an array of size n, in the worst case.

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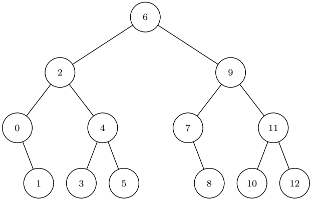

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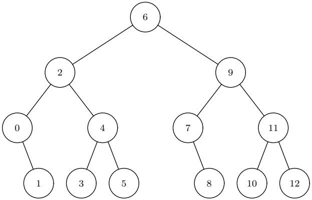

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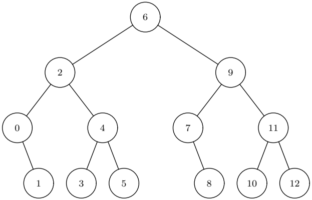

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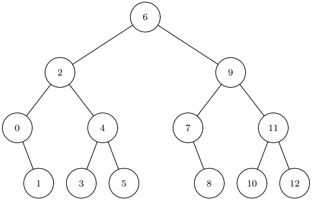

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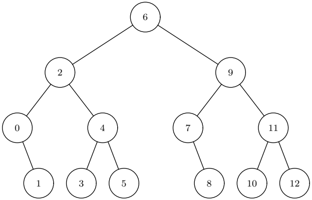

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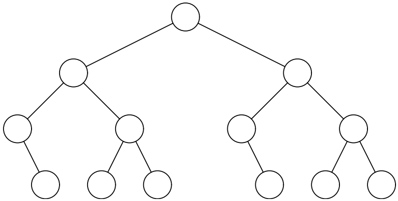

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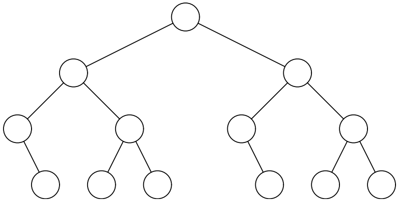

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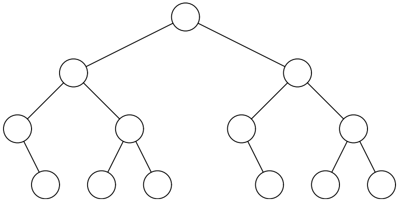

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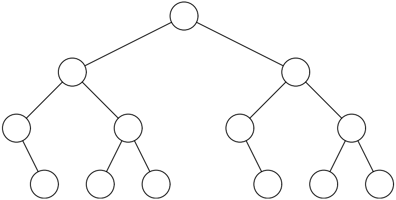

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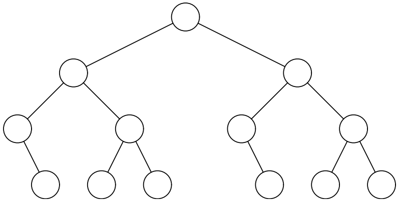

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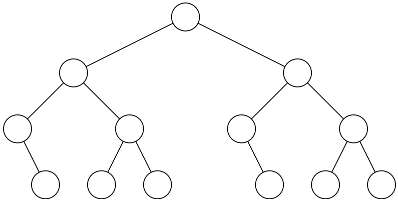

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So binary search is optimal with respect to worst-case performance.

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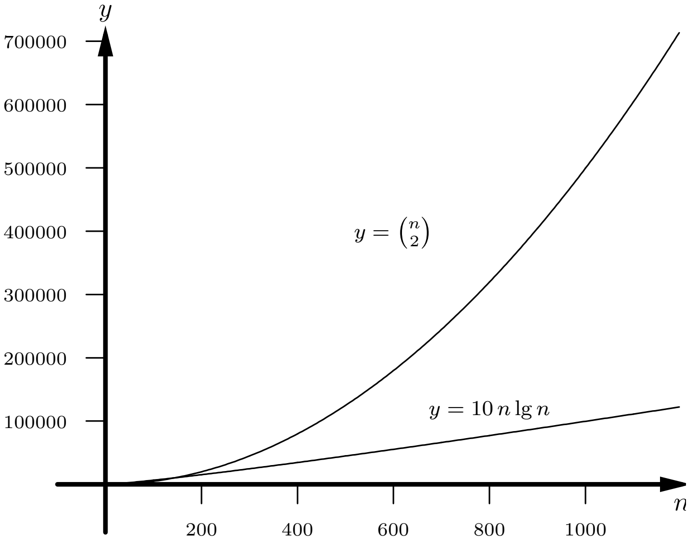
- Comparison-based sorting has lower bound of $\Omega(n \log n)$ comparisons. (We will prove this.)

$\Theta(n \log n)$ work vs. quadratic ($\Theta(n^2)$) work



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Example: The list

$$18 \quad 29 \quad 12 \quad 15 \quad 32 \quad 10$$

has 9 inversions:

$$\{(18,12),\ (18,15),\ (18,10),\ (29,12),\ (29,15),\ (29,10),\ (12,10),\ (15,10),\ (32,10)\}$$

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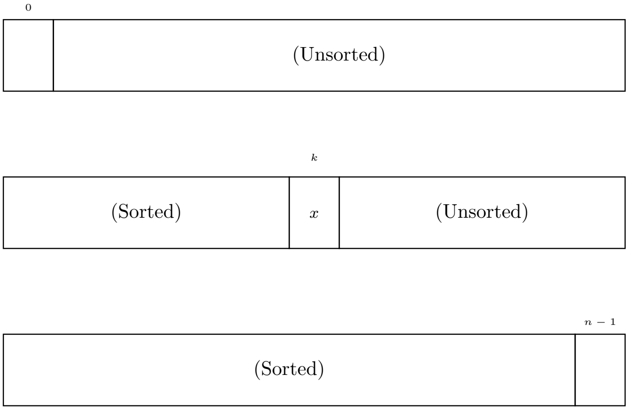
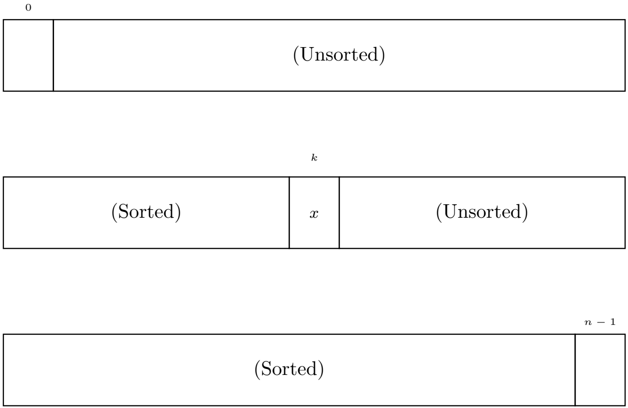


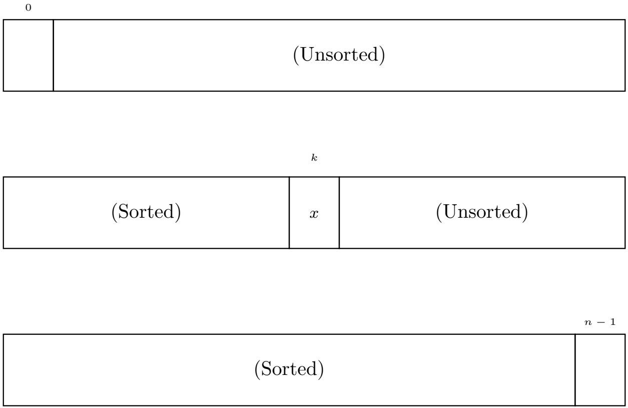
Insertion sort

- Work from left to right across array

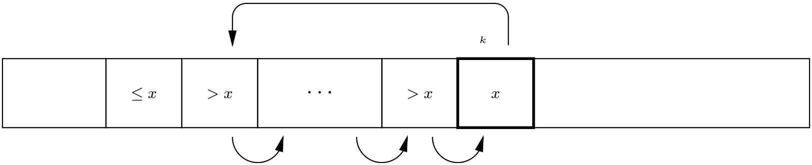


Insertion sort

- Work from left to right across array
- Insert each item in correct position with respect to (sorted) elements to its left



Insertion sort pseudocode




```
def insertionSort(n, A):
    for k = 1 to n-1:
        x = A[k]
        j = k-1
        while (j >= 0) and (A[j] > x):
            A[j+1] = A[j]
            j = j-1
        A[j+1] = x
```

Insertion sort example

23	19	42	17	85	38

23	19	42	17	85	38

19	23	42	17	85	38

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17	19	23	42	85	38

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- Storage: in place: $O(1)$ extra storage

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