

## DYNAMIC Search Problems

- Input: Set of “keyed” records  $S$
- Operations:
  - Add record to  $S$
  - Delete record from  $S$
  - Find record in  $S$  with  $\text{key}=x$  (if one exists)

CS14013-1

## Dictionary Data Structure

Data structure that supports add, delete, find for set of keyed records.

- Binary search tree
  - Balanced binary search tree
- General search tree
- Hash Table

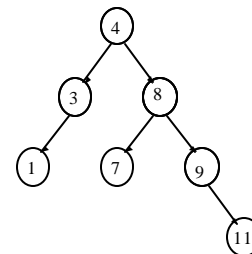
CS14013-2

## Binary Search Tree for $S$

- $T$  is a binary tree
- 1-1 relationship between the nodes in  $T$  and the records in  $S$
- BST Property: For any node  $X$  in  $T$ 
  - For any node  $Y$  in the left subtree of  $X$ ,  $Y.\text{key} \leq X.\text{key}$
  - For any node  $Y$  in the right subtree of  $X$ ,  $Y.\text{key} \geq X.\text{key}$

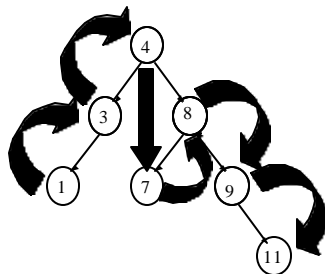
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## BST



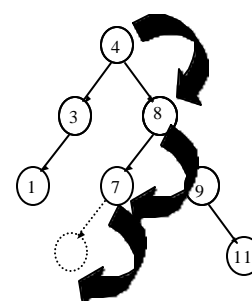
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## Sorting with BST



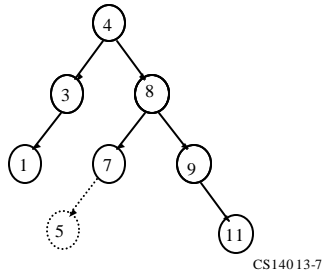
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## Insert (5)

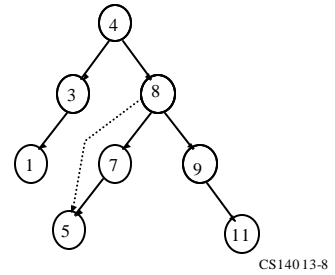


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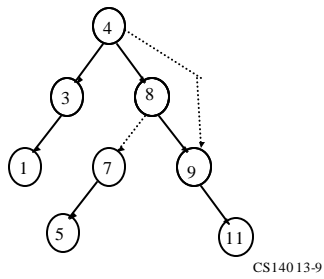
### Delete(5) (Leaf is easy)



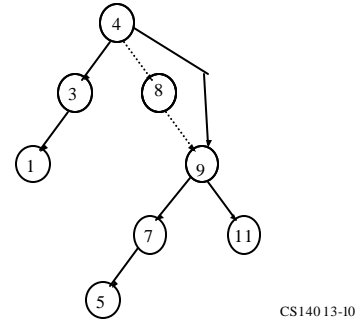
### Delete(7) (Node with 1 child is easy)



### Delete(8) - Step 1



### Delete(8) - Step 2



### Operation Run Time

- Search(x)                   – O(h)
- Insert(x)                   – O(h)
- Delete(x)                   – O(h)

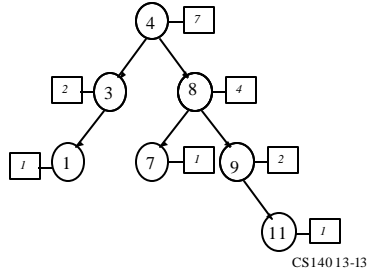
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### Rank

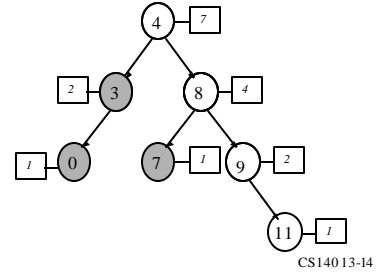
- How can we add rank-finding to the dictionary data structure?
- For each node x in T:
  - count(x) is the number of nodes in the subtree rooted at x.

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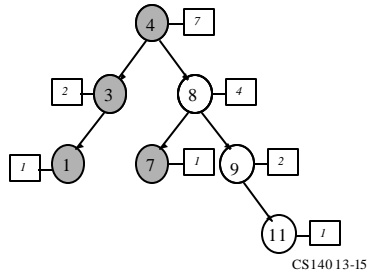
### BST with rank capability



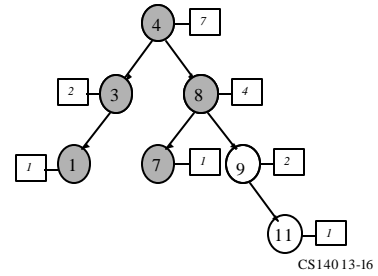
### Rank(3)=2



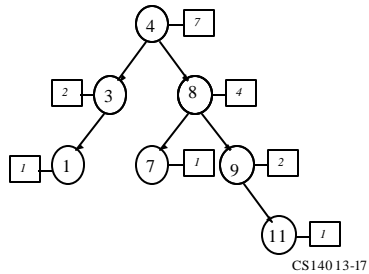
### Rank(7)=4



### Rank(8)=5



### Find-rank(5)=8



### Operation Run Time

- Search(x)                   – O(h)
- Insert(x)                   – O(h)
- Delete(x)                  – O(h)
- Rank(x)                    – O(h)
- Search-rank(i)            – O(h)

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## Keeping a good balance ...

- Search trees:  $O(n)$  time per operation
- “Balanced trees” insure  $O(\log n)$  time per operation.
- Different approaches to balance:
  - Red/black trees
  - 2-3 trees
  - AVL trees

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## Balancing Act

- How can we maintain count during balancing act?
- Do as homework!

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