Symbol Tables

Computing 2 COMP1927 16x1

SYMBOL TABLES

- Searching: like sorting, searching is a fundamental element of many computational tasks
  - data bases
  - dictionaries
  - compiler symbol tables
- Symbol table: a symbol table is a data structure of items with keys that supports at least two basic operations:
  - insert a new item (key,value)
    - (student id, student data) – in a database
    - (word, meaning) – in a dictionary
  - return an item identified by a given key

Abstracting over concrete Item and Key type

- We abstract over the concrete item type by defining these types and some basic operations on them in a separate header file, Item.h:

```
typedef int Key;

struct record {
  Key keyval;
  char value[10];
};

typedef struct record *Item;

#define key(A)  ((A)->keyval)
#define eq(A,B)   {A == B}
#define less(A,B) {A < B}
#define NULLitem  NULL  // special value for no item

int ITEMscan (Item *); // read from stdin
int ITEMshow (Item);   // print to stdout
```

SYMBOL TABLE AS ABSTRACT DATA TYPE

- Symbol Table ADT:

```
typedef struct symbolTable *ST;

// new symbol table
ST  STinit (void);

// number of items in the table
int STcount (ST);

// insert an item
void STinsert (ST, Item);

// find item with given key
Item STsearch (ST, Key);

// delete given item
void STdelete (ST, Item);

//  find nth item
Item STselect (ST, int);

// visit items in order of their keys
void STsort (ST, void (*visit)(Item));
```

Symbol Table as Abstract Data Type

- How do we deal with duplicate keys?
  - depends on the application:
    - Do not allow duplicates
      - Insertion of duplicates does nothing – fails silently
      - Insertion of duplicates returns an error
    - store all items with the same key in one entry in the symbol table
    - store duplicates as separate entries in the symbol table
- Our approach will not allow duplicates and ignore attempts to insert them.

A SIMPLE SYMBOL TABLE CLIENT PROGRAM

- We start by writing a simple client program:
  - reads items from stdin
  - insert item if not yet in table
  - print resulting table in order
  - print out the smallest, largest and median values.

SYMBOL TABLE IMPLEMENTATIONS

- Symbol tables can be represented in many ways:
  - key-indexed array (max # items, restricted key space)
  - key-sorted arrays (max # items, using binary search)
  - linked lists (unlimited items, sorted list?)
  - binary search trees (unlimited items, traversal orders)
- Costs (assuming *N* items):

Type	Search Cost Min	Max	Average
Key Indexed Array	O(1)	O(1)	O(1)
Key sorted Array	O(1)	O(log n)	O(log n)
Linked List	O(1)	O(n)	O(n)
Binary Search Tree	O(1)	O(n)	O(log n)

IMPLEMENTATION : KEY INDEXED ARRAY

- Use key to determine index position in the array
  - requires dense keys (i.e., few gaps)
  - keys must be integral (or easy to map to integral value)
- Properties:
  - insert, search and delete are constant time O(1)
  - init, select, and sort are linear in table size

	[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]
items	NULLitem	1,data	NULLitem	3,data	4,data	5,data	NULLitem	7,data

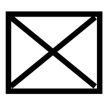
Implementation : Binary Search Trees

- Binary tree:
  - key (and maybe items) in internal nodes
  - key in a node is
    - larger than any key in its left subtree
    - smaller than any key in its right subtree
- Properties:
  - init & count are constant time
  - insert, delete, search & select are logarithmic in the number of stored items in average case, linear in worst case (degenerate tree)
  - sort linear in numbers of stored items

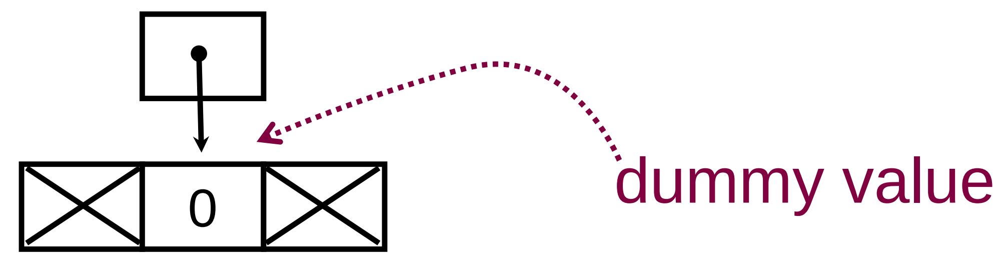
IMPLEMENTATION : BINARY SEARCH TREES

- In our implementation, we use a dummy node to represent empty trees
- Representation of an empty tree:

previously:

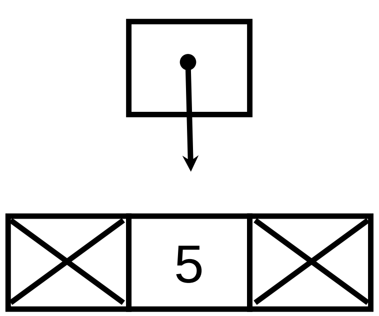


new implementation :

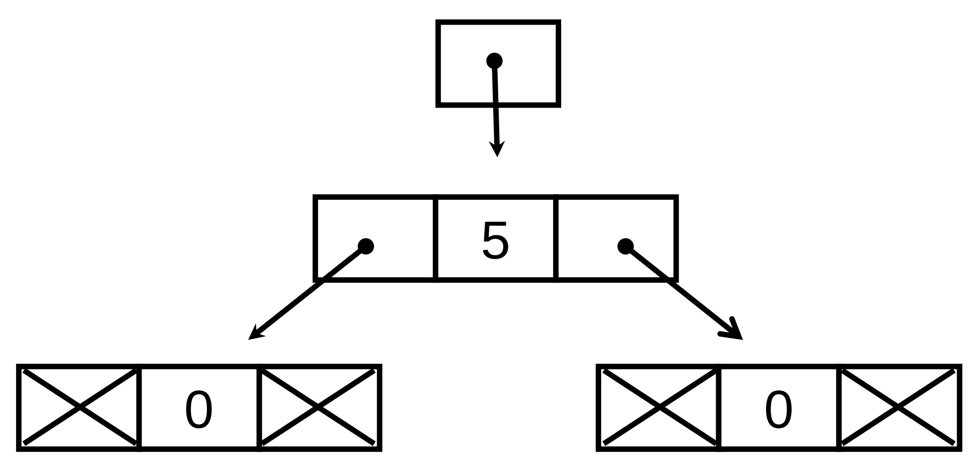


- Representation of a tree with a single value node:

previously:

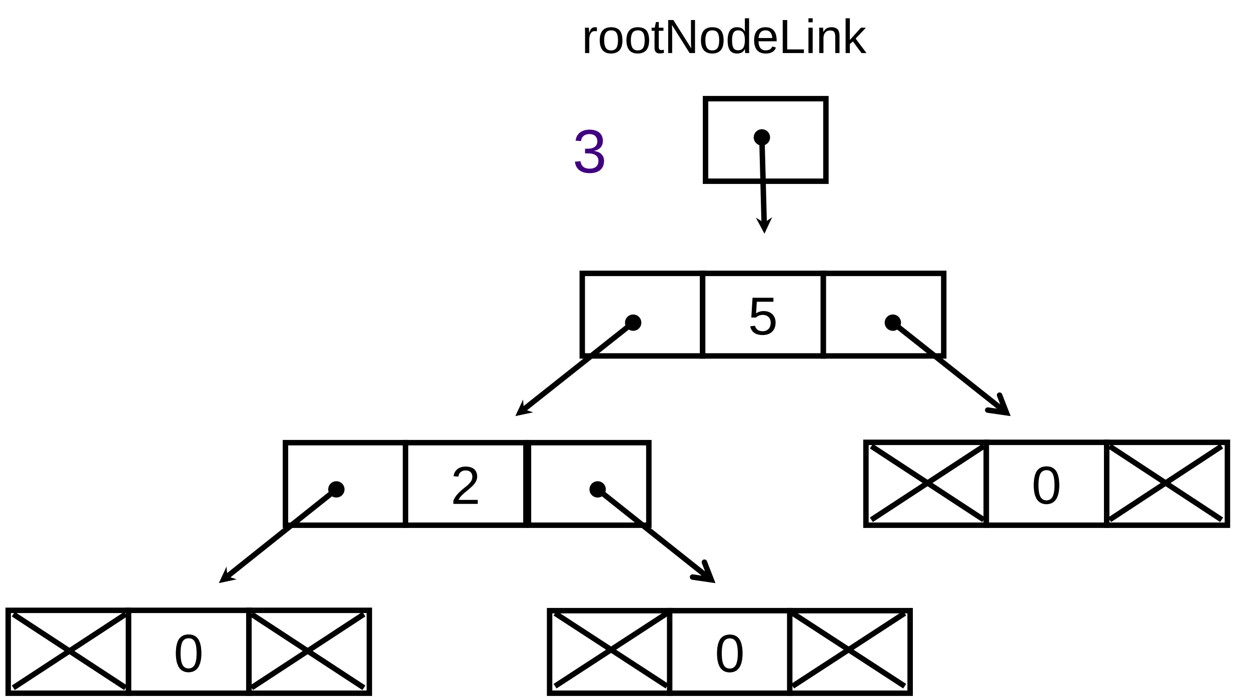


new implementation :



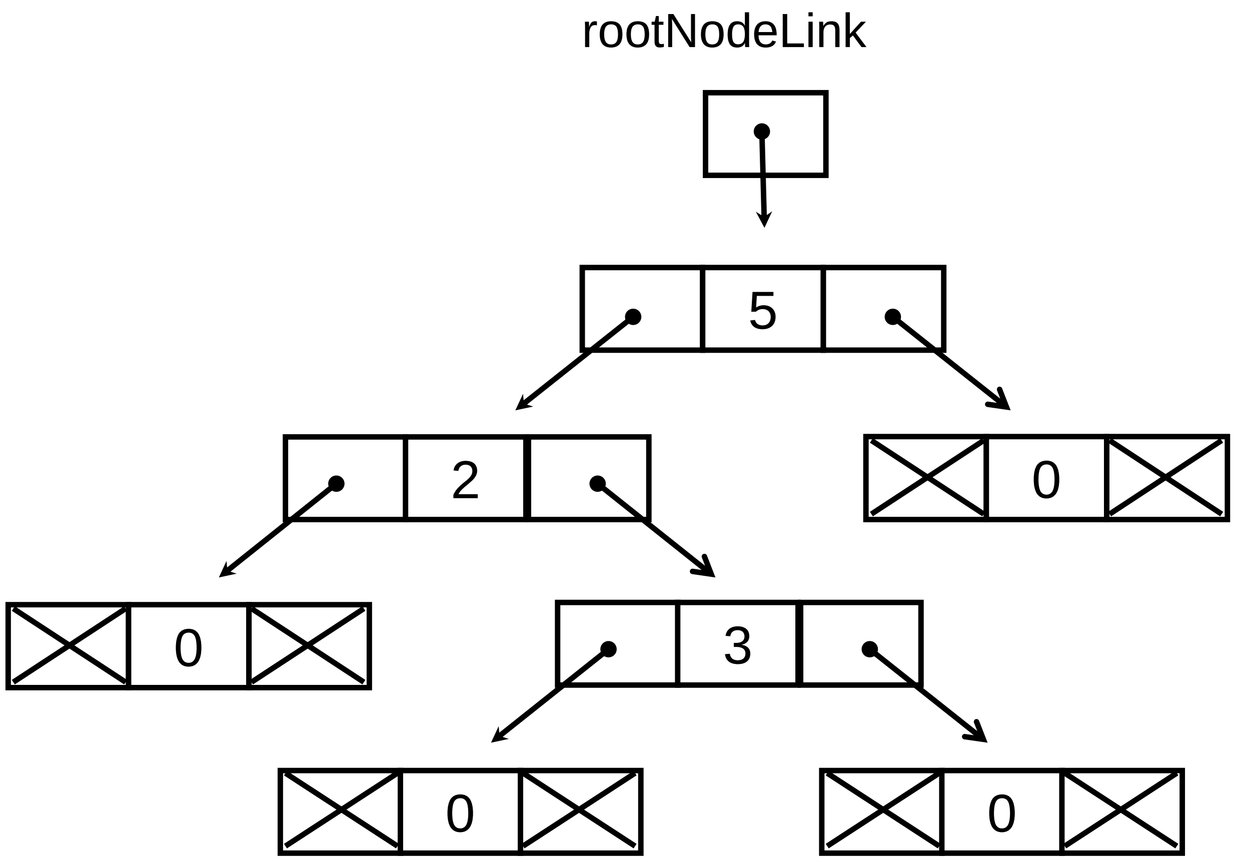
Binary Search Tree: insertion of new node

- Insert item with key '3' into tree:



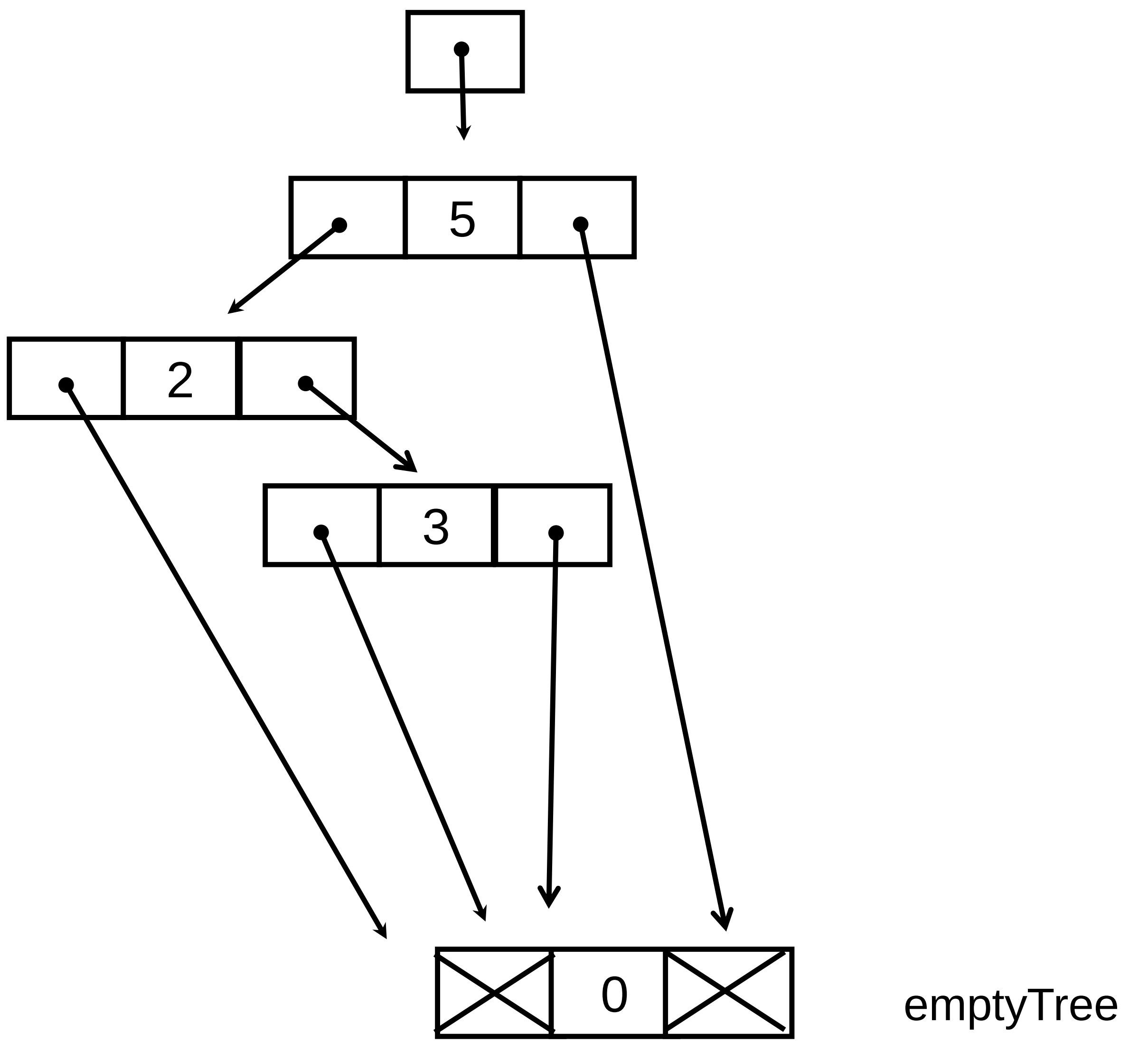
BINARY SEARCH TREE: INSERTION OF NEW NODE

- Insert item with key ‘3’ into tree:



BINARY SEARCH TREE

- To save space, all the empty subtrees are actually represented by the same struct:



IMPLEMENTATION : BINARY SEARCH TREES

- :In our implementation, we use a dummy node to represent empty trees:

```
struct st{
   link root;
}
typedef struct STnode* link;

struct STnode {
    Item item;
    link left,;
    link right;
    int size; //Size of sub-tree rooted at this node
};

static link emptyTree = NULL;      // dummy node representing empty tree
static link newNode(Item item, link l, link r, int size);

ST STinit (void) {
     ST st = malloc(sizeof(struct st));
     if(emptyTree == NULL) //only one actual copy of emptyTree is ever created
          emptyTree = newNode(NULLitem, NULL, NULL, 0);
     st->root = emptyTree;
     return st;
}
```

Implementation : Binary Search Trees

- Implementation of recursive insertion:

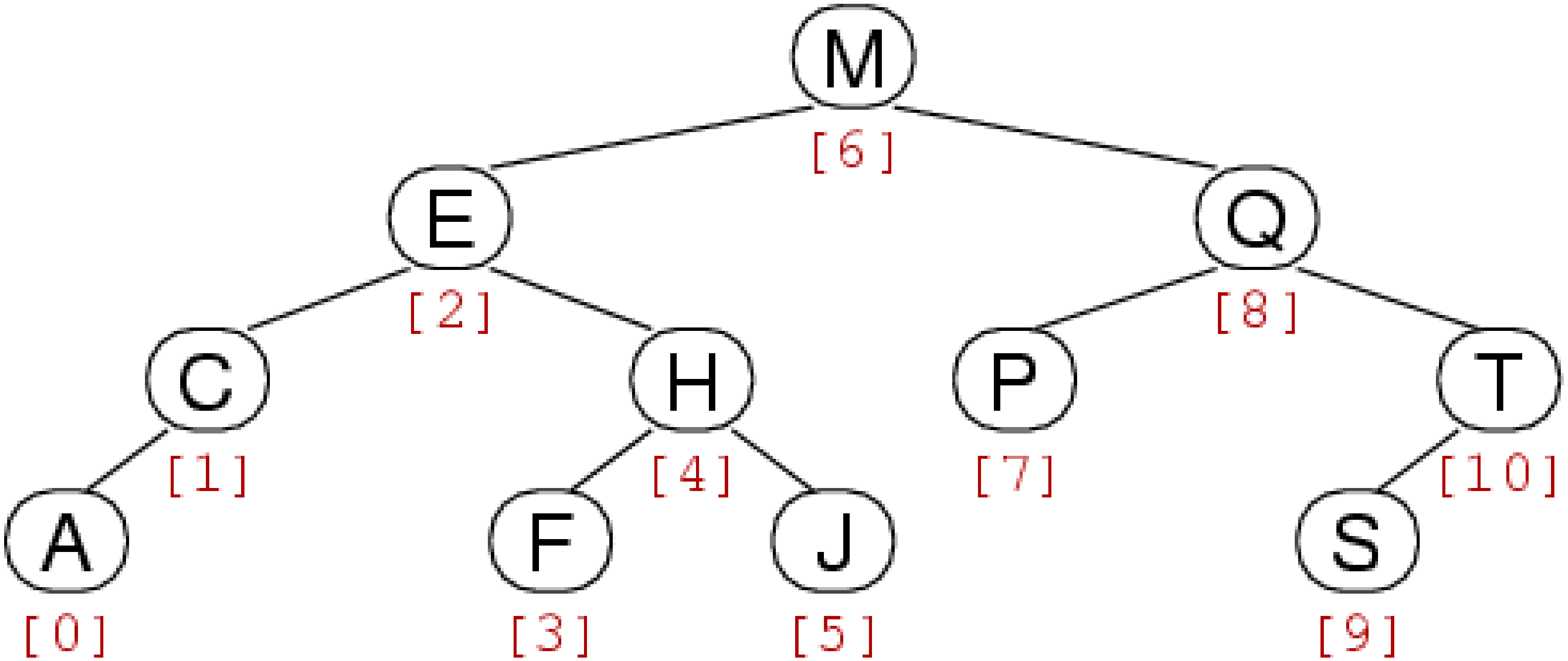
```
link insertR (link currentLink, Item item) {
    Key v = key (item);
    Key currentKey = key (currentLink->item);

   if (currentLink == emptyTree) {
        return newNode(item, emptyTree, emptyTree, 1);
    }

    if (less(v, currentKey)) {
        currentLink->left = insertR (currentLink->left, item);
    } else {
        currentLink->right = insertR (currentLink->right, item);
    }
   (currentLink->size)++;
    return currentLink;
}
```

BST: SELECT

- How can we select the kth smallest element of a search tree?
- Can be done quite easily if we store the size of the subtree in each node (start with 0)
  - *Base case 1:* if tree is empty tree
    - search was unsuccessful
  - *Base case 2:* if left subtree has k items
    - return node item
  - *Recursive case 1:* left subtree has $m > k$ items
    - continue search of kth item in left subtree
  - *Recursive case 2:* left subtree has $m < k$ items
    - continue search of $(k\text{-}m\text{-}1)th$ item in right subtree

SELECT KTH ITEM

- For a tree with N Nodes, indexes are 0..N-1



Implementation : Binary Search Trees

- Implementation of select

```
static Item selectR (link currentTree, int k) {
      if (currentTree == emptyTree) {
          return NULLitem;
      }
     if (currentTree->left->size == k) {
          return (currentTree->item);
     }

     if (currentTree->left->size > k) {
          return (selectR (currentTree->left, k));
      }

      return (selectR (currentTree->right, k - 1 - currentTree->left->size));
}

Item STselect (ST s,int k) {
      return (selectR (s->root, k));
}
```

PERFORMANCE CHARACTERISTICS OF BSTS

- We already discussed the performance of binary search trees:
  - on average,
    - O($log\ n$) steps to search, insert in a tree with n items
  - worst case (degenerate tree)
    - O(n) steps

Symbol Tables as Indexes

- Scenario:
  - large set of items;
  - need efficient access via key
  - but also need sequential access to items
  - items might be stored in very large array or file
- Solution:
  - leave items in place
  - use symbol table holding (key,ref) pairs
  - Commonly used as an access mechanism in databases.