# CS 2211
# Systems Programming

## Part Twelve:

## Trees

# Basic Tree Concepts

*We begin with a discussion of the terminology used with trees*

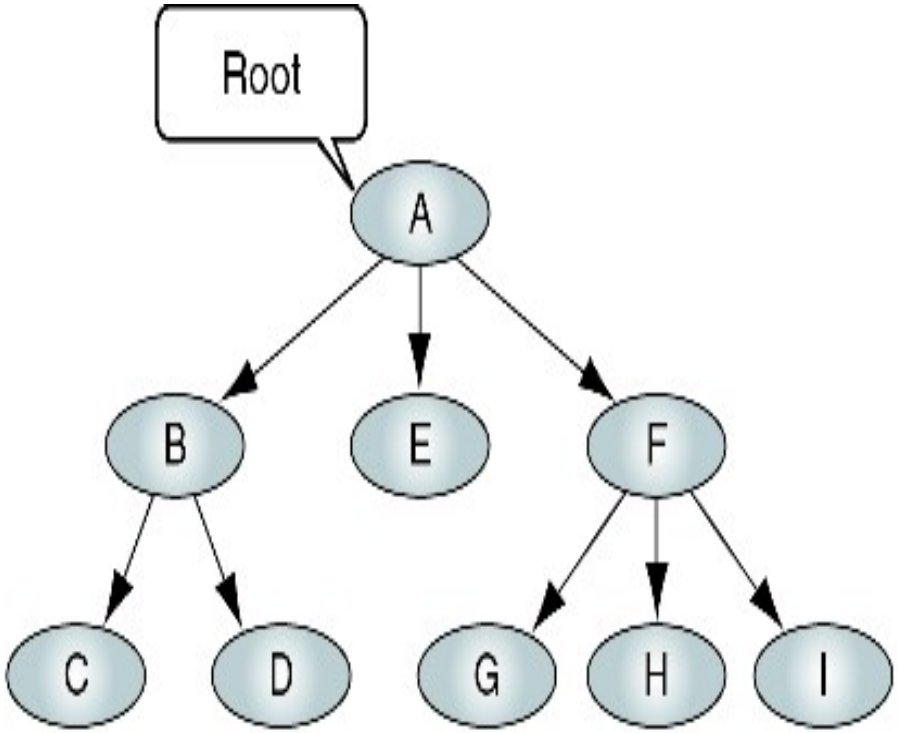



FIGURE 6-1 Tree

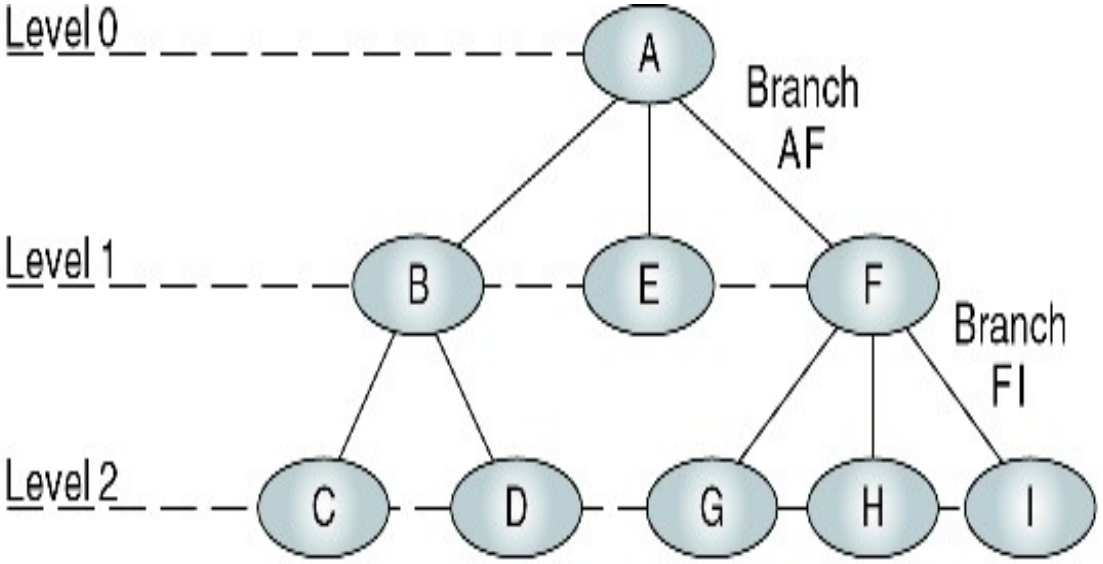



FIGURE 6-2 Tree Nomenclature

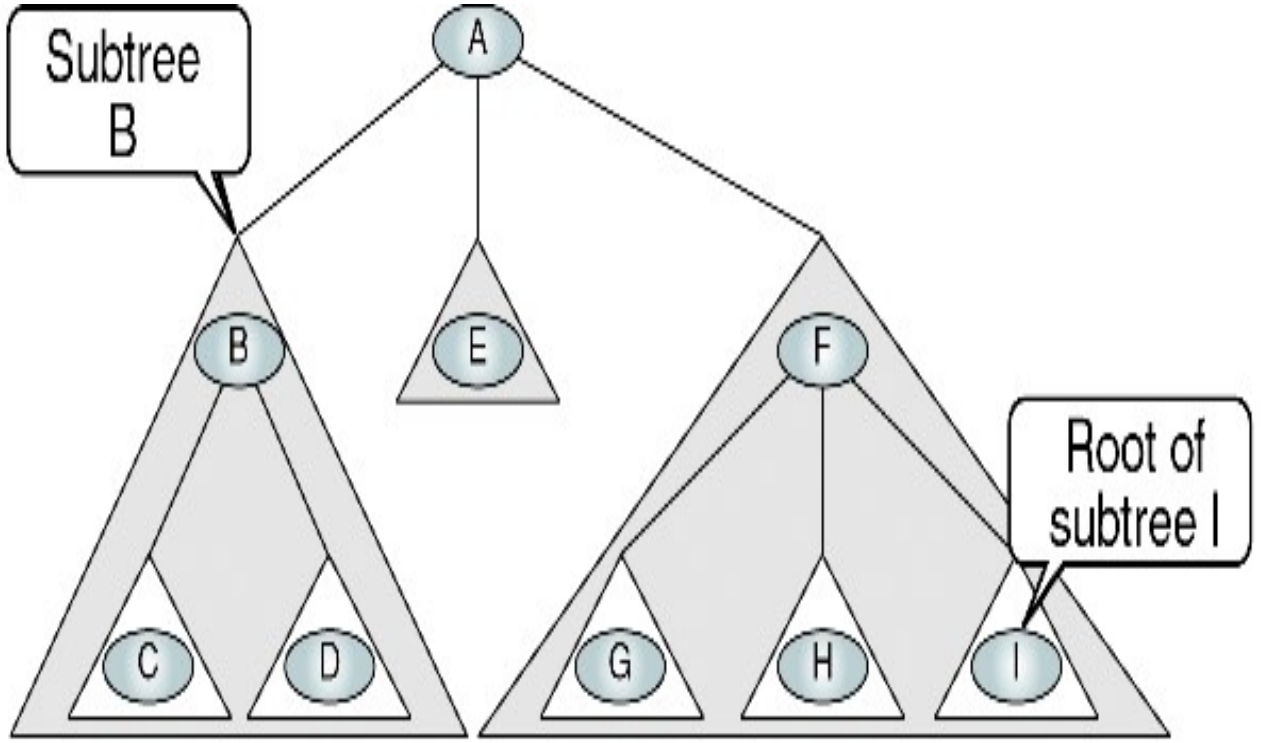



FIGURE 6-3 Subtrees

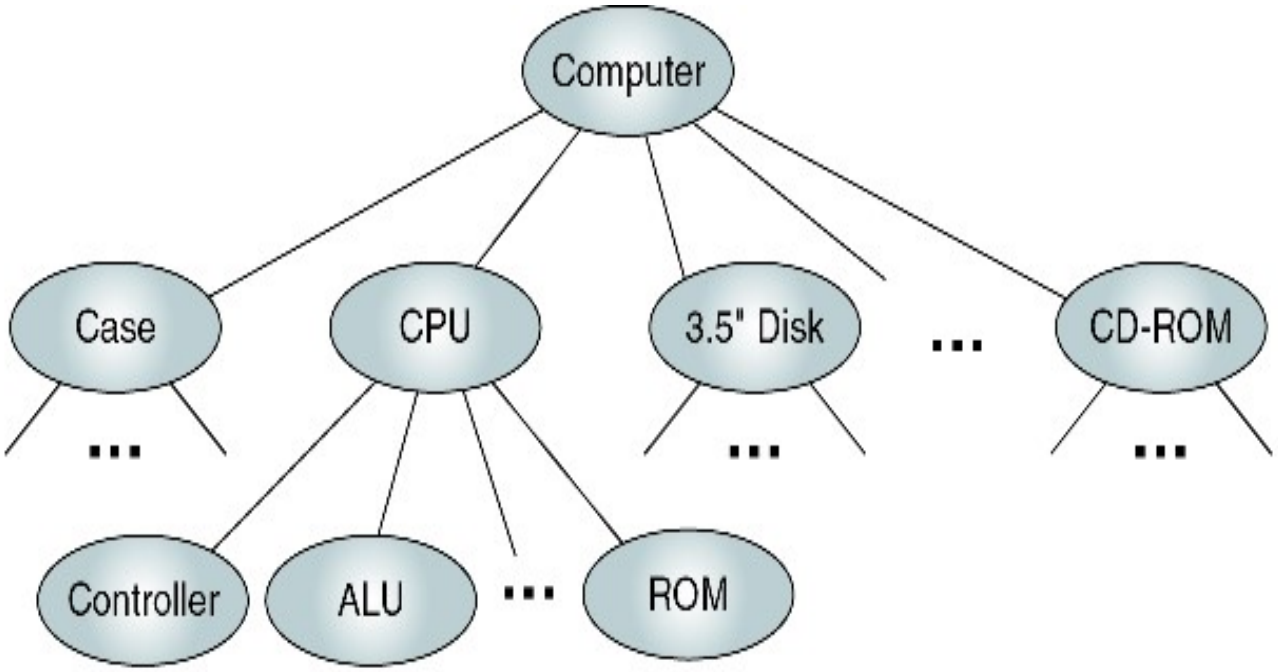



FIGURE 6-4 Computer Parts List as a General Tree

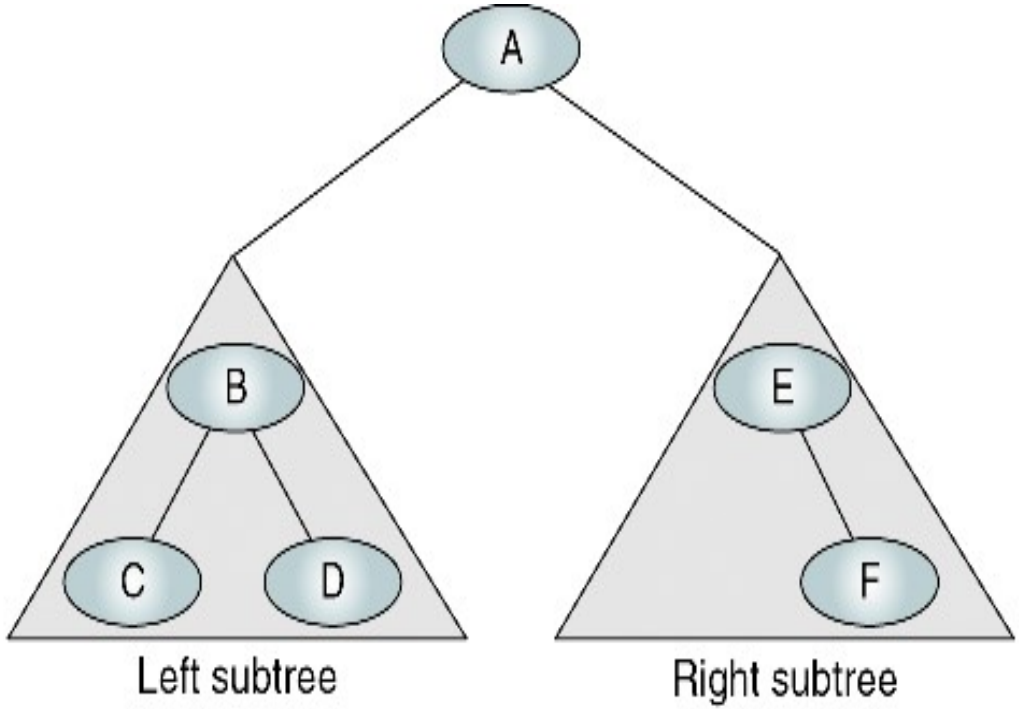



FIGURE 6-5 Binary Tree

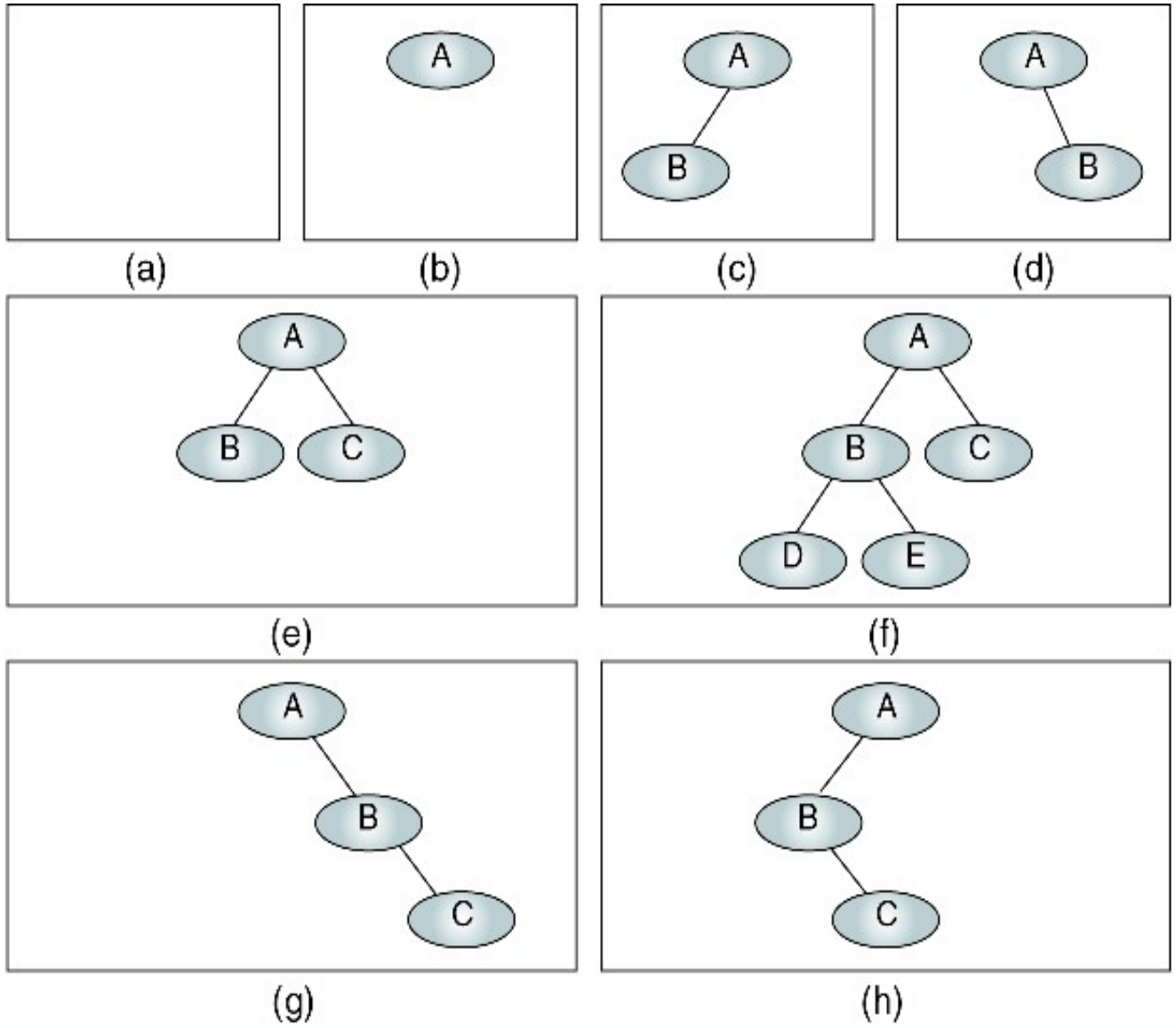
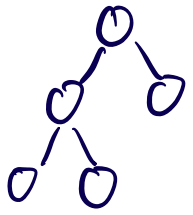


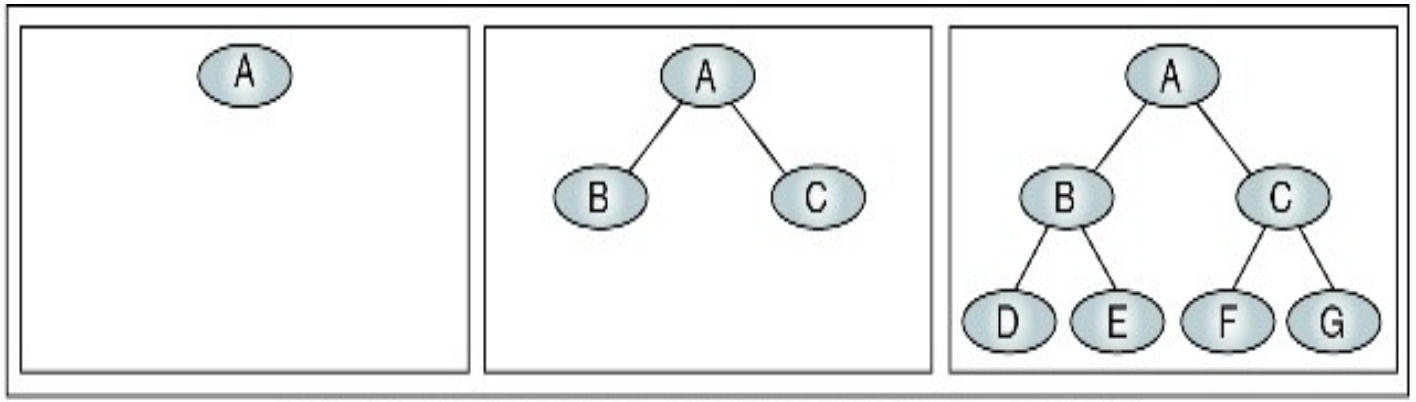

FIGURE 6-6 Collection of Binary Trees

完全二叉树：若深度为k，
则各层(1~k-1)结点树达到最大，第k层连续集中在最左侧.

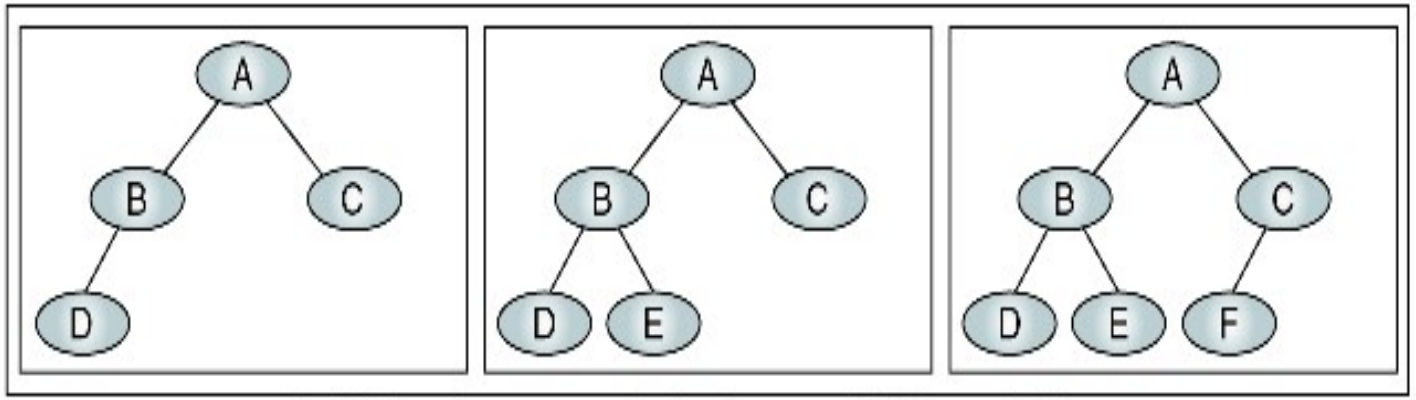
e.g



这也是一种完全二叉树.



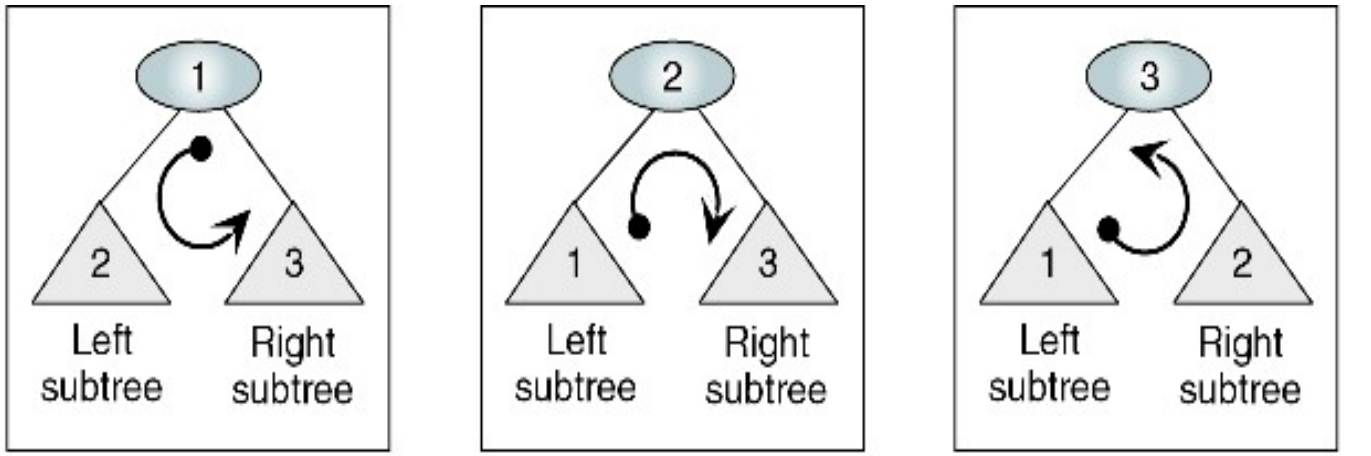

(a) Complete trees (at levels 0, 1, and 2)




(b) Nearly complete trees (at level 2)

FIGURE 6-7 Complete and Nearly Complete Trees

Out -> L -> R  L -> Out -> R  L -> R -> Out.




(a) Preorder traversal (b) Inorder traversal (c) Postorder traversal

FIGURE 6-8 Binary Tree Traversals

*Binary search trees provide an excellent structure for searching a list*
*- and -*
*at the same time for inserting and deleting data into the list.*

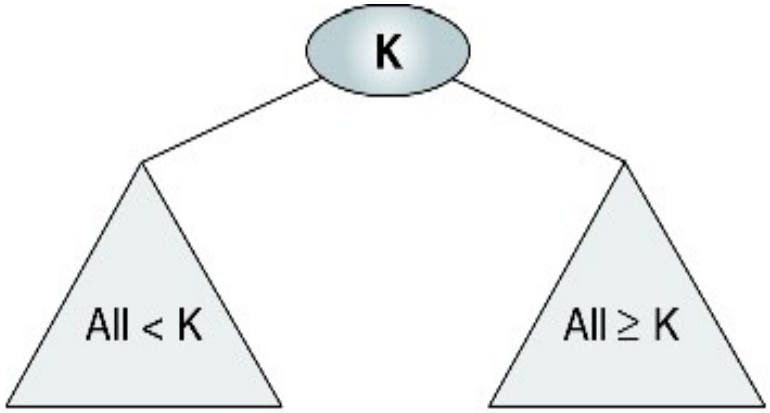



FIGURE 7-1 Binary Search Tree

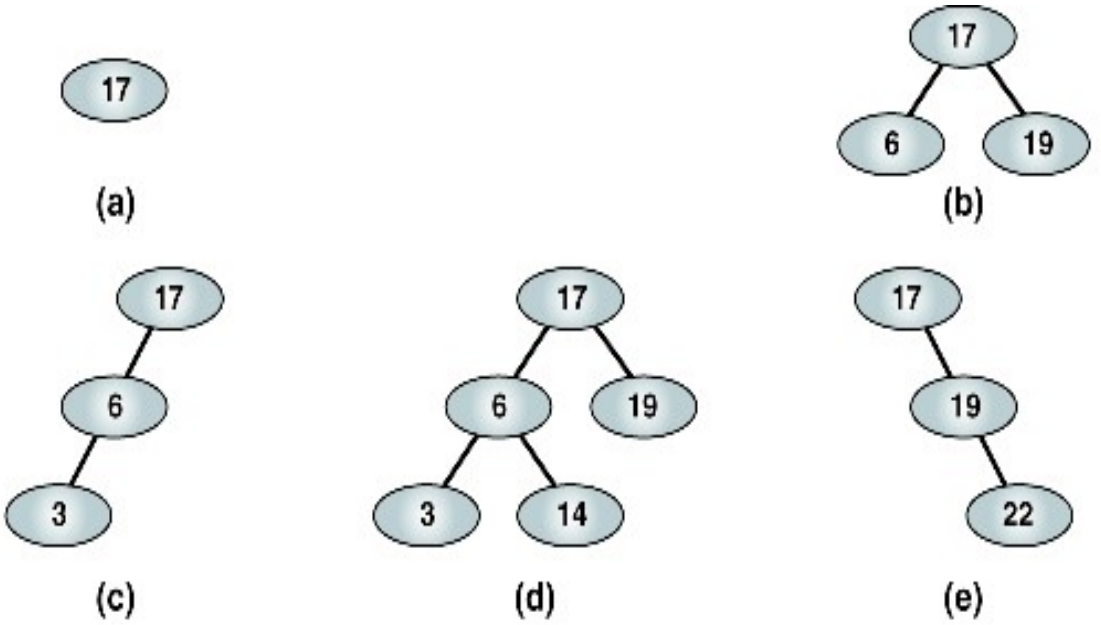



FIGURE 7-2 Valid Binary Search Trees

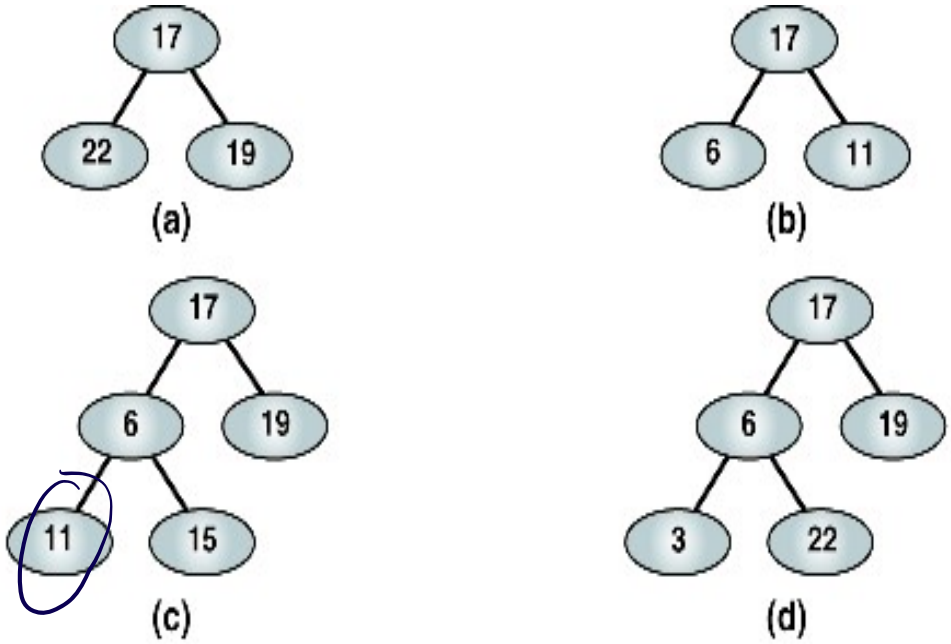



FIGURE 7-3 Invalid Binary Search Trees

# Trees in C

**END OF PART 1**

# 7-2 BST Operations

*We discuss four basic BST operations: traversal, search, insert, and delete; and develop algorithms for searches, insertion, and deletion.*

- Traversals
- Searches
- Insertion
- Deletion

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- Insertion
- Traversals
- Searches
- Deletion

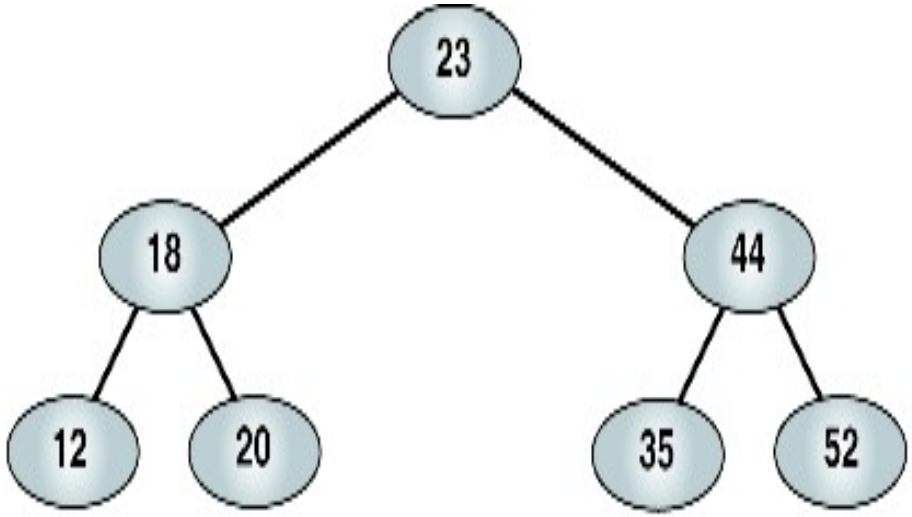
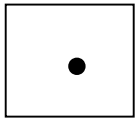



FIGURE 7-4 Example of a Binary Search Tree

# To Add an Item to an Empty BST

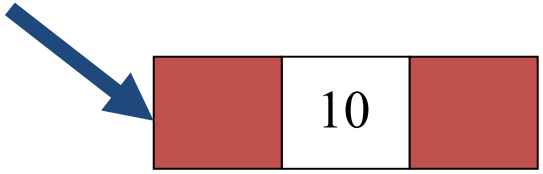
BSTree

root



compare

Build the new node, and put the new data item in it



# To Add an Item to an Empty BST

BSTree

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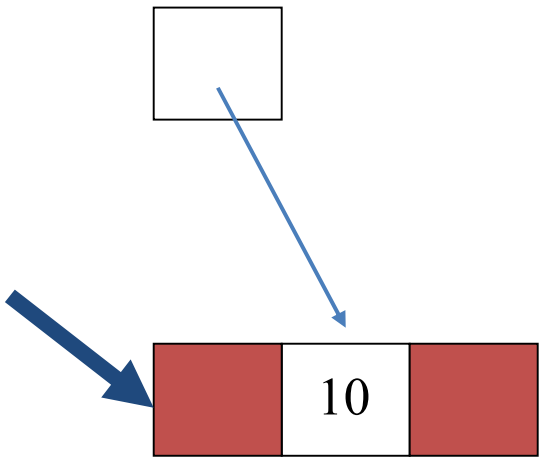


*REMEMBER: the node definition for a doubly linked list was:*

```
typedef struct node
{
          int               data;
          struct node*      next;
          struct node*      prev;
} NODE;
```


*… the node definition for a binary search tree is simply:*

```
typedef struct node
{
          int               data;
          struct node*      right;
          struct node*      left;
} NODE;
```

*Based on the node definition – to create a new node:*

```
typedef struct node
{
          int               data;
          struct node*      right;
          struct node*      left;
} NODE;
```

*- to create a new node: :*

```
struct node *newNode(int item)
{
    struct node *leaf = (struct node *)malloc(sizeof(struct node));
    leaf->data = item;
    leaf->left = leaf->right = NULL;

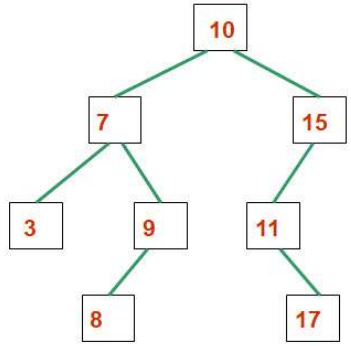
    return leaf;
}
```

```
#include "defs.h"

int main()
{
// Local Definitions

    struct node *root = NULL;
    ...
    ...

}    // main
```




| Label | Address | Value |
|---|---|---|
| | ... | |
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**defs.h**

```
#include<stdio.h>
#include<stdlib.h>

typedef struct
{
    struct node *root;
    int count;
} TREE;

//         Prototype Declarations

struct node *newNode(int );
struct node* insert(struct node*, int );
struct node * minValueNode(struct node* );
struct node* deleteNode(struct node*, int );
void printPostorder(struct node* );
void printInorder(struct node* );
void printPreorder(struct node* );
```

```
#include "defs.h"


int main()
{
   ...
   struct node *root = NULL;
   root = insert(root, 10);
   ...

}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
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| | ... | |
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| data | 564 - 567 | 10 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
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| | ... | |
| | ... | |
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| | ... | |
| item | 620 - 623 | 10 |
| | ... | |
| | ... | |
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| | ... | |
| item | 620 - 623 | 10 |
| | ... | |
| temp | 660 - 663 | 1010 |
| | ... | |
| { DM } | 1010 - 1021 | |
| | ... | |
| | ... | |
| | ... | |
| | | |
| | | |

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| item | 620 - 623 | 10 |
| | ... | |
| temp | 660 - 663 | 1010 |
| | ... | |
| data | 1010 - 1013 | 10 |
| { DM } | 1014 - 1021 | |
| | ... | |
| | ... | |
| | | |
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| temp | 660 - 663 | 1010 |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
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BSTinsert.c

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    return node;
}
```

1010

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|---|---|---|
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| | ... | |
| node | 560 - 563 | NULL |
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| temp | 660 - 663 | 1010 |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
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```

**1010**

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| data | 564 - 567 | 10 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |

```
#include "defs.h"


int main()
{
    ...
    struct node *root = NULL;
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   ...

}    // main
```

1010

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BSTinsert.c

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}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
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    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
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    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
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    return temp;
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    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
        node->left = insert(node->left, data);
    else
        node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
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    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
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struct node* insert(struct node* node, int data)
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    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| item | 610 -613 | 7 |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| | ... | |
| | | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| item | 610 -613 | 7 |
| temp | 614 -617 | 1230 |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| { DM } | 1230 - 1041 | |
| | | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
        node->left = insert(node->left, data);
    else
        node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| item | 610 -613 | 7 |
| temp | 614 -617 | 1230 |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| data | 1230 - 1233 | 7 |
| { DM } | 1010 - 1021 | |
| | | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
        node->left = insert(node->left, data);
    else
        node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| item | 610 -613 | 7 |
| temp | 614 -617 | 1230 |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| data | 1230 - 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 - 1241 | NULL |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
        node->left = insert(node->left, data);
    else
        node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

**1230**

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| item | 610 -613 | 7 |
| temp | 614 -617 | 1230 |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 – 1241 | NULL |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

**1230**

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| node | 590 - 593 | NULL |
| data | 594 - 597 | 7 |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | NULL |
| right | 1018 - 1021 | NULL |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 – 1241 | NULL |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
        node->left = insert(node->left, data);
    else
        node->right = insert(node->right, data);

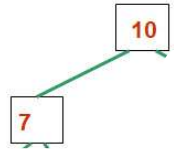
    /* return the (unchanged) node pointer */
    return node;
}
```

1230

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | NULL |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 – 1241 | NULL |
| | | |

```c
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```




**BSTinsert.c**

```c
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
        node->left = insert(node->left, data);
    else
        node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

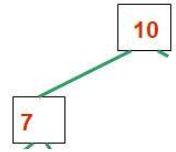
**10100**

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| node | 560 - 563 | 1010 |
| data | 564 - 567 | 7 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | NULL |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 – 1241 | NULL |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```

10100




BSTinsert.c

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

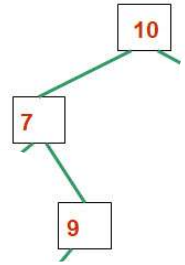
    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | NULL |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 – 1241 | NULL |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
   ...
}    // main
```




**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

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struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

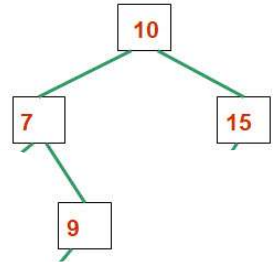
    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | NULL |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | NULL |
| right | 1428 – 1431 | NULL |
| | ... | |
| | ... | |
| | ... | |
| | | |

```
#include "defs.h"

int main()
{
    ...
    struct node *root = NULL;
    root = insert(root, 10);
    root = insert(root, 7);
    root = insert(root, 9);
    root = insert(root, 15);
    ...
}    // main
```




**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

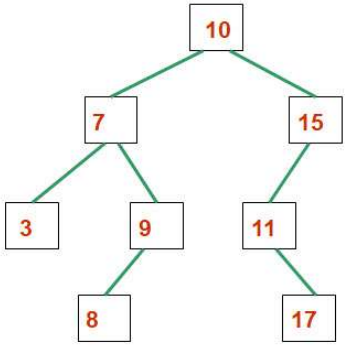
    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

    /* return the (unchanged) node pointer */
    return node;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | NULL |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | NULL |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | NULL |
| right | 1758 – 1761 | NULL |
| | | |

```
#include "defs.h"

int main()
{
   ...
   root = insert(root, 11);
   root = insert(root, 3);
   root = insert(root, 8);
   root = insert(root, 14);
   ...
}    // main
```




**BSTinsert.c**

```
// A utility function to create a new BST node
struct node *newNode(int item)
{
    struct node *temp = (struct node *)malloc(sizeof(struct node));
    temp->data = item;
    temp->left = temp->right = NULL;
    return temp;
}

/* A utility function to insert a new node with given data in BST */
struct node* insert(struct node* node, int data)
{
    /* If the tree is empty, return a new node */
    if (node == NULL) return newNode(data);

    /* Otherwise, recur down the tree */
    if (data < node->data)
         node->left = insert(node->left, data);
    else
         node->right = insert(node->right, data);

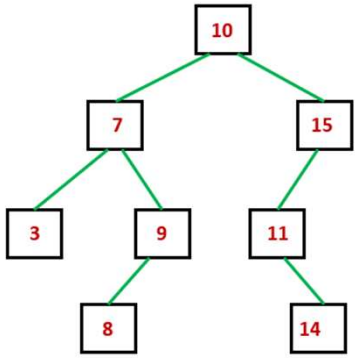
    /* return the (unchanged) node pointer */
    return node;
}
```

# Trees in C

**END OF PART 2**

```
#include "defs.h"

int main()
{
   ...
   printf("\nPreorder traversal of binary tree is \n");
        printPreorder(root);
   ...
}    // main
```




**BSTTransvers.c**

```
/* Given a binary tree, print its nodes in preorder*/
void printPreorder(struct node* node)
{
            if (node == NULL)
                        return;

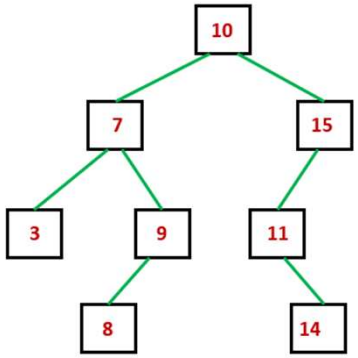
            /* first print data of node */
            printf("%d ", node->data);

            /* then recur on left sutree */
            printPreorder(node->left);

            /* now recur on right subtree */
            printPreorder(node->right);
}
```

```
#include "defs.h"

int main()
{
   ...
   printf("\nPreorder traversal of binary tree is \n");
        printPreorder(root);
   ...
}    // main
```




BSTTransvers.c

```
/* Given a binary tree, print its nodes in preorder*/
void printPreorder(struct node* node)
{
            if (node == NULL)
                        return;

            /* first print data of node */
            printf("%d ", node->data);

            /* then recur on left sutree */
            printPreorder(node->left);

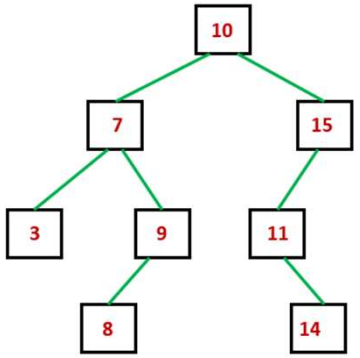
            /* now recur on right subtree */
            printPreorder(node->right);
}
```

**10 – 7 – 3 – 9 – 8 – 15 – 11 - 14**

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

```
#include "defs.h"

int main()
{
   ...
   printf("\nInorder traversal of binary tree is \n");
          printInorder(root);
   ...
}    // main
```




**BSTTransvers.c**

```
void printInorder(struct node* node)
{
            if (node == NULL)
                        return;

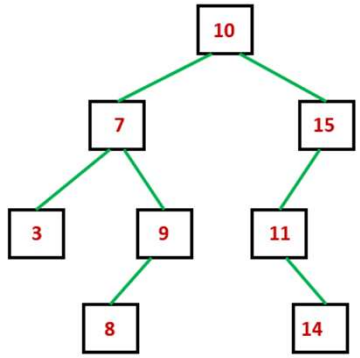
            /* first recur on left child */
            printInorder(node->left);

            /* then print the data of node */
            printf("%d ", node->data);

            /* now recur on right child */
            printInorder(node->right);
}
```

```
#include "defs.h"

int main()
{
   ...
   printf("\nInorder traversal of binary tree is \n");
          printInorder(root);
   ...
}    // main
```




**BSTTransvers.c**

```
void printInorder(struct node* node)
{
            if (node == NULL)
                        return;

            /* first recur on left child */
            printInorder(node->left);

            /* then print the data of node */
            printf("%d ", node->data);

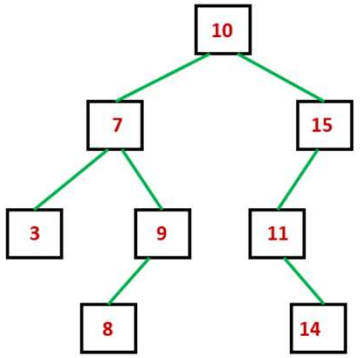
            /* now recur on right child */
            printInorder(node->right);
}
```

**3 – 7 – 8 – 9 – 10 – 11 – 14 - 15**

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

```
#include "defs.h"

int main()
{
   ...
   printf("\nPostorder traversal of binary tree is \n");
        printPostorder(root);
   ...
}    // main
```




**BSTTransvers.c**

```
/* Given a binary tree, print its nodes according to the
"bottom-up" postorder traversal. */
void printPostorder(struct node* node)
{
            if (node == NULL)
                        return;

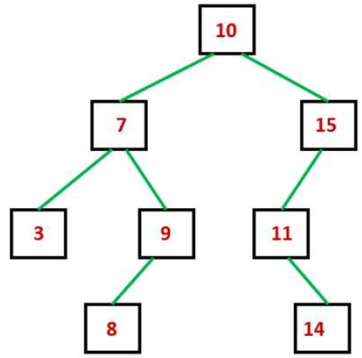
            // first recur on left subtree
            printPostorder(node->left);

            // then recur on right subtree
            printPostorder(node->right);

            // now deal with the node
            printf("%d ", node->data);
}
```

```
#include "defs.h"

int main()
{
   ...
   printf("\nPostorder traversal of binary tree is \n");
        printPostorder(root);
   ...
}    // main
```




BSTTransvers.c

```
/* Given a binary tree, print its nodes according to the
"bottom-up" postorder traversal. */
void printPostorder(struct node* node)
{
            if (node == NULL)
                        return;

            // first recur on left subtree
            printPostorder(node->left);

            // then recur on right subtree
            printPostorder(node->right);

            // now deal with the node
            printf("%d ", node->data);
}
```

**3 – 8 – 9 – 7 – 14 – 11 – 15 – 10**

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

# Trees in C

**END OF PART 3**

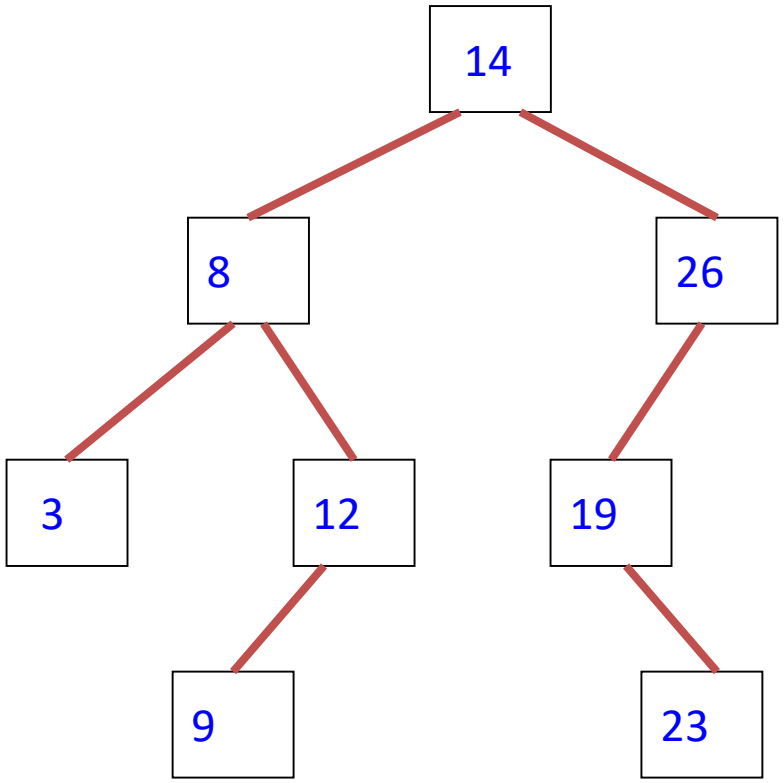
# Searching in a BST

- Why is it called a binary ***search*** tree?
  - Data is stored in such a way, that it can be more ***efficiently*** found than in an ordinary binary tree

# Searching in a BST

- **Algorithm to *search* for an item in a BST**
  - Compare data item to the root of the (sub)tree
  - If data item = data at root, found
  - If data item < data at root, go to the left; if there is no left child, data item is not in tree
  - If data item > data at root, go to the right; if there is no right child, data item is not in tree

# Search Operation – a Recursive Algorithm




*To search for a value k;*

*returns true if found*
*or false if not found*

If the tree is empty, return false.

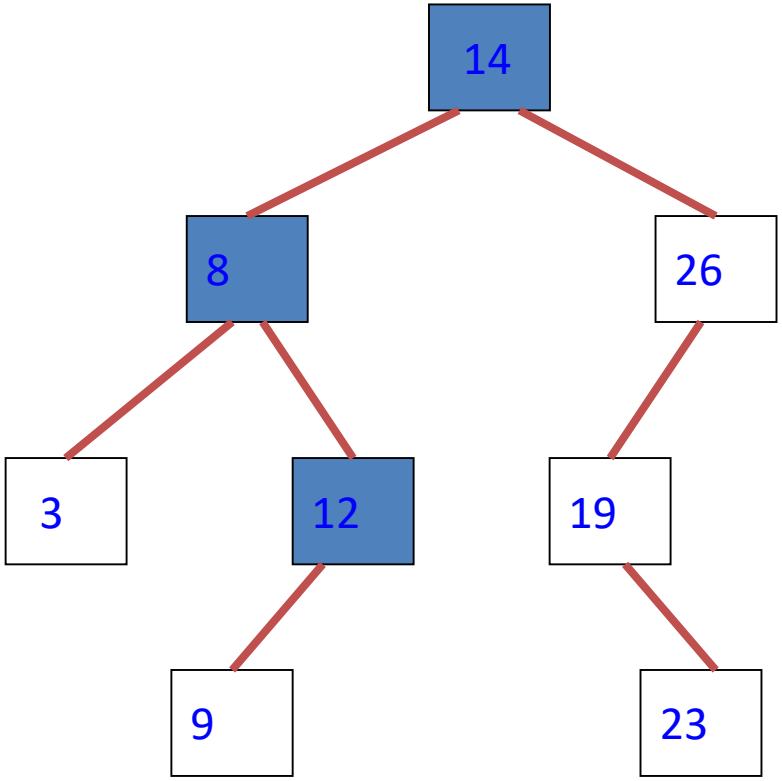
If k == value at root

return true: we're done.

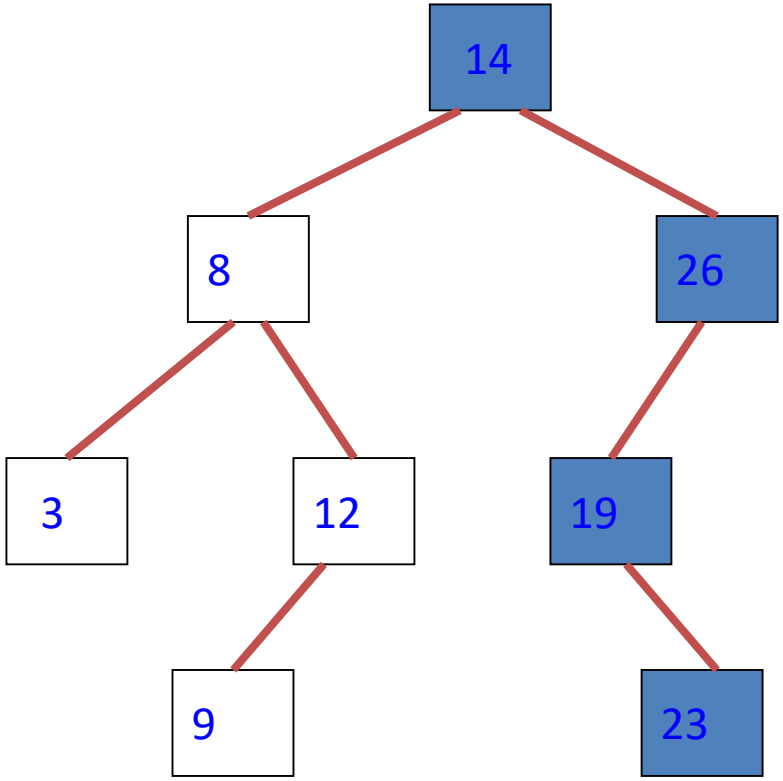
If k < value at root
return result from search for k in
the left subtree

Else
return result from search for k in
the right subtree.

# Search Operation

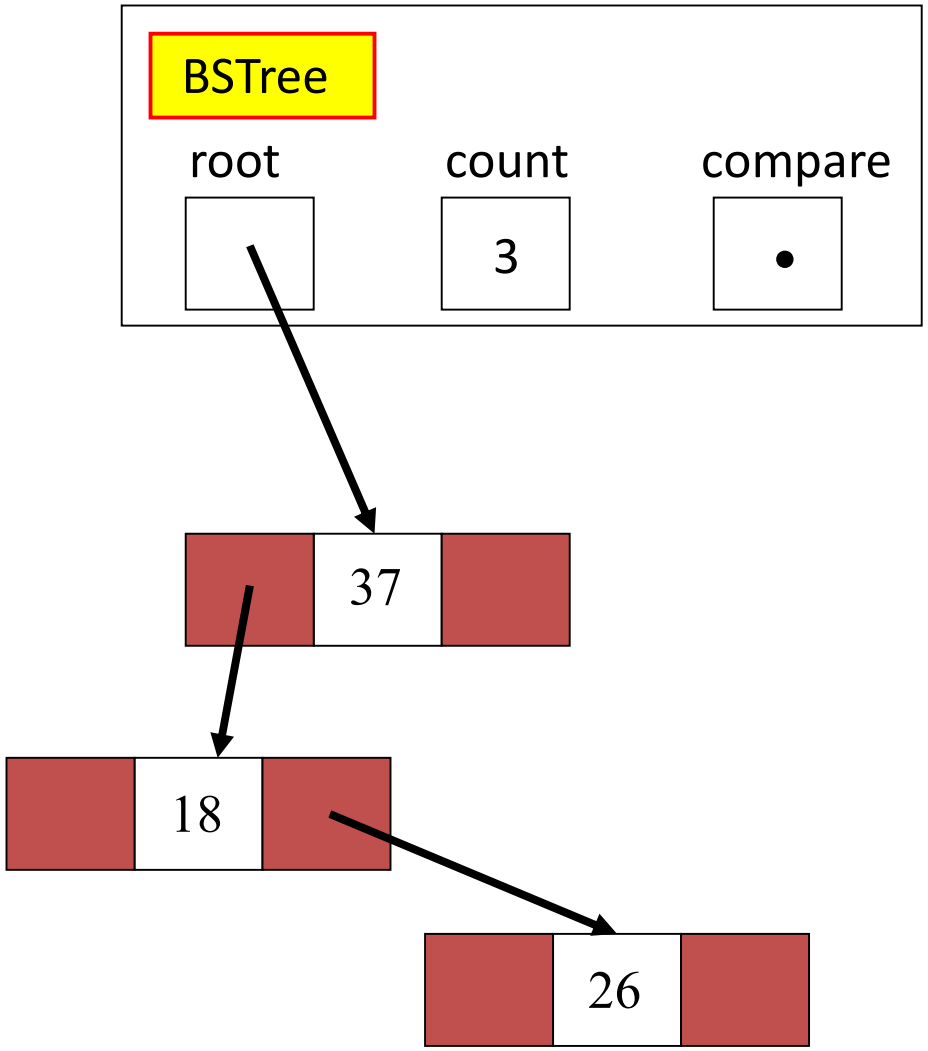



*Search for 13*: visited nodes are coloured yellow; return false when node containing 12 has no right child




*Search for 22*: return false when node containing 23 has no left child

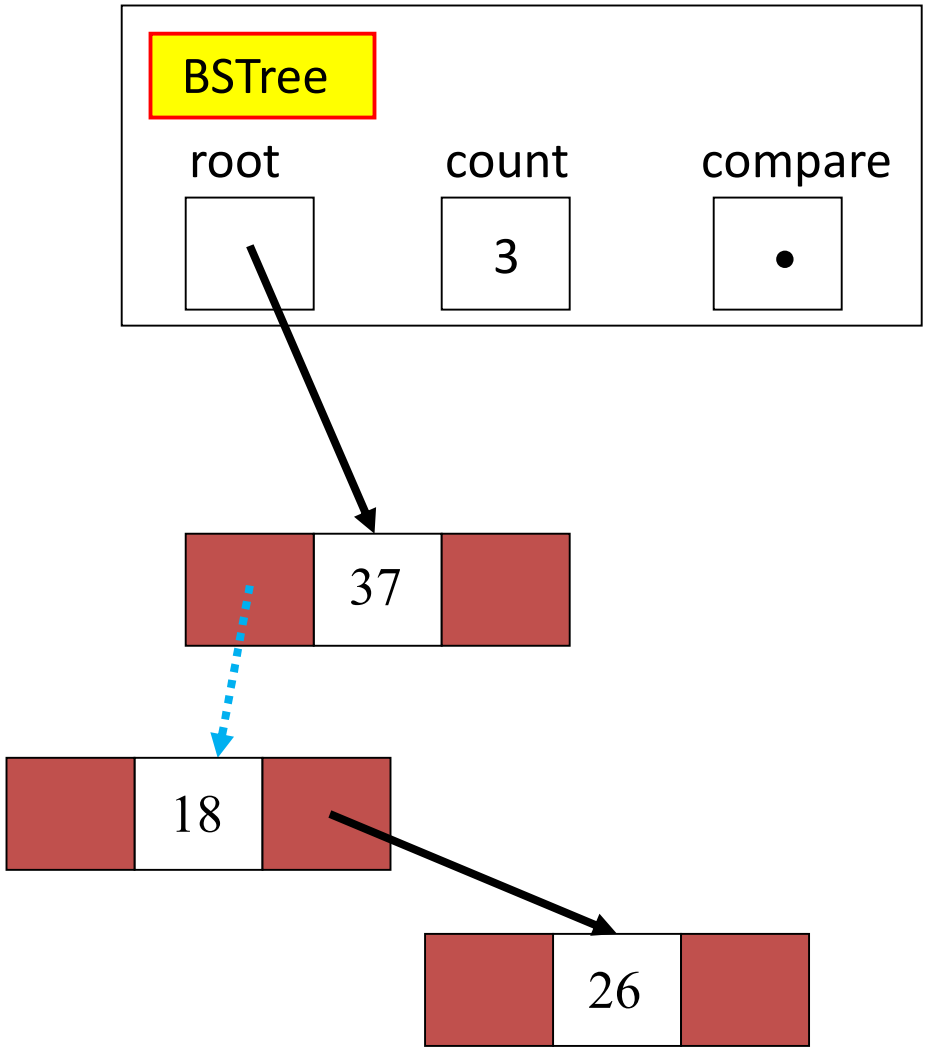
# Search for a NODE on the BST




start at the root

If less – search left node
if greater – search right node
if equal – return location
else
return ‘not found’

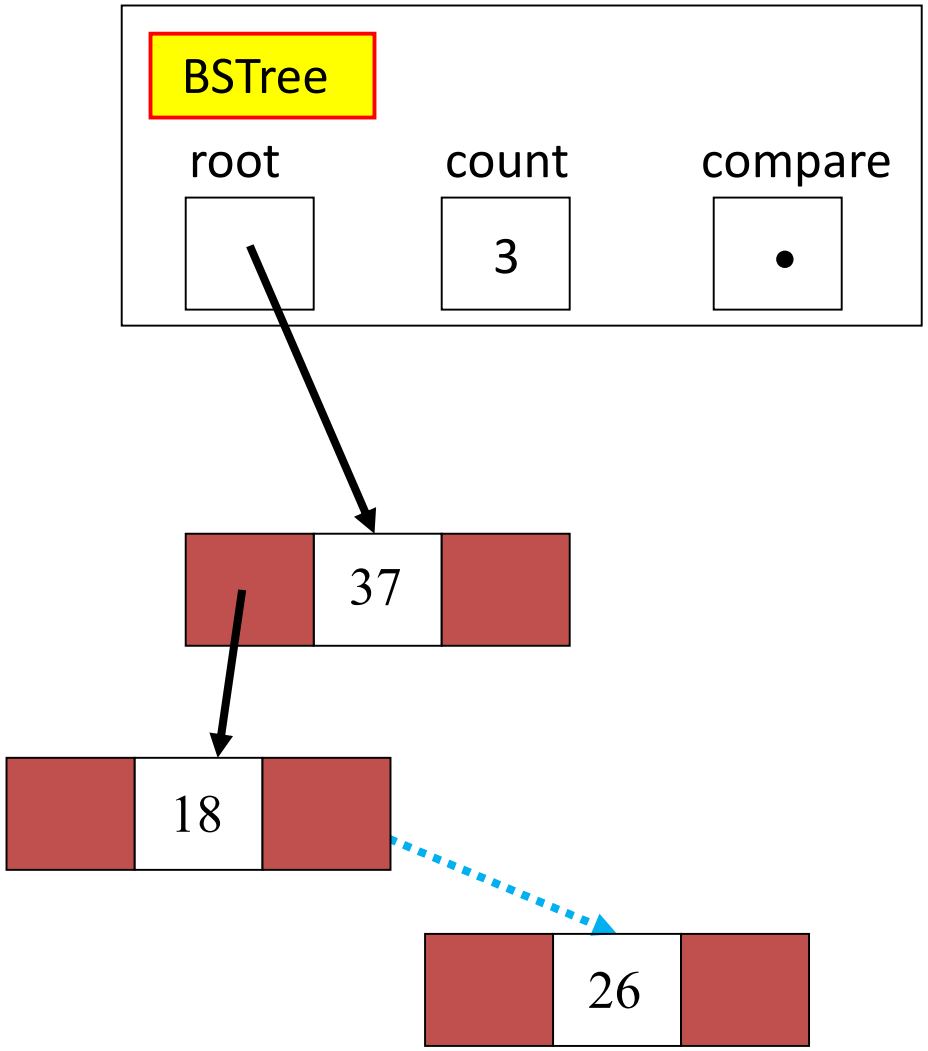
# Search for a NODE on the BST




start at the root

If less – search left node
if greater – search right node
if equal – return location
else
return ‘not found’

# Search for a NODE on the BST



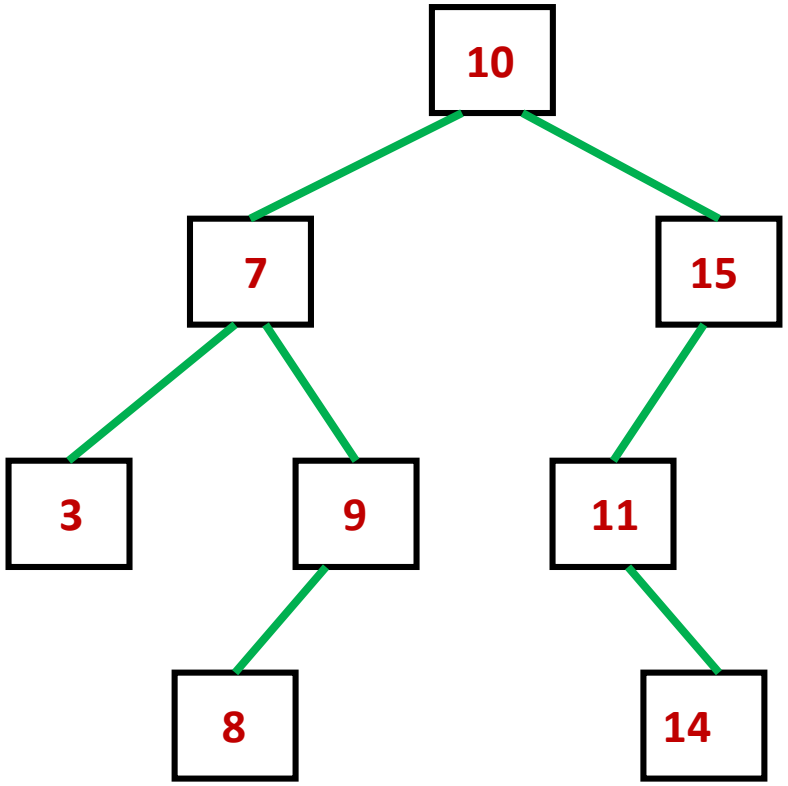

start at the root

If less – search left node
if greater – search right node
if equal – return location
else
return ‘not found’

# Trees in C

**END OF PART 4**

# Delete Operation – a Recursive Algorithm

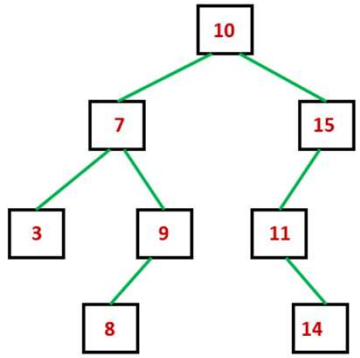



```
delete (recursively)
If ( root == NULL)  return root


If (data < root->data);
  delete root->left
else if  (data > root->data);
  delete root->right
else
   if (root->left is NULL);
      *temp = root->right
       free(root)
    else if (root->left is NULL);
       *temp = root->left
        free(root)

find the smallest leaf to the right from this point
switch values
 delete unused node
```

```
...
  printf("\nDelete 7\n");
  root = deleteNode(root, 7);
...
```




**BSTDelete.c**

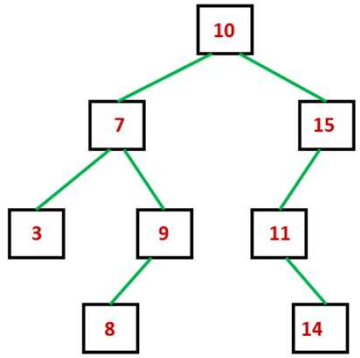
```
/* Given a binary search tree and a data, this function deletes the data
and returns the new root */
struct node* deleteNode(struct node* root, int data)
{
   if (root == NULL) return root;

   if (data < root->data)
       root->left = deleteNode(root->left, data);
   else if (data > root->data)
           root->right = deleteNode(root->right, data);
   else
   {
        if (root->left == NULL)
           struct node *temp = root->right;
           free(root);
           return temp;
        }
        else if (root->right == NULL)
        {
           struct node *temp = root->left;
           free(root);
           return temp;
        }

        struct node* temp = minValueNode(root->right);
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
     }
     return root;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| | ... | |
| | ... | |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

```
...
  printf("\nDelete 7\n");
  root = deleteNode(root, 7);
 ...
```




**BSTDelete.c**

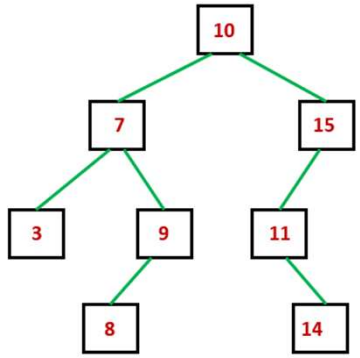
```
/* Given a binary search tree and a data, this function deletes the data
and returns the new root */
struct node* deleteNode(struct node* root, int data)
{
    if (root == NULL) return root;

    if (data < root->data)
        root->left = deleteNode(root->left, data);
    else if (data > root->data)
            root->right = deleteNode(root->right, data);
    else
    {
         if (root->left == NULL)
            struct node *temp = root->right;
            free(root);
            return temp;
         }
         else if (root->right == NULL)
         {
            struct node *temp = root->left;
            free(root);
            return temp;
         }

         struct node* temp = minValueNode(root->right);
         root->data = temp->data;
         root->right = deleteNode(root->right, temp->data);
      }
      return root;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| root | 500 - 503 | 10100 |
| data | 504 -507 | 7 |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

```
...
  printf("\nDelete 7\n");
  root = deleteNode(root, 7);
 ...
```




**BSTDelete.c**

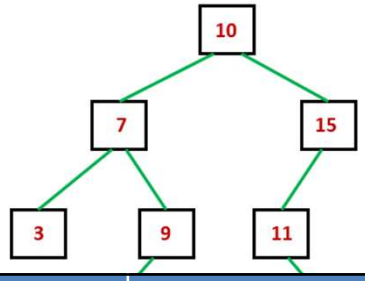
```
/* Given a binary search tree and a data, this function deletes the data
and returns the new root */
struct node* deleteNode(struct node* root, int data)
{
   if (root == NULL) return root;

   if (data < root->data)
       root->left = deleteNode(root->left, data);
   else if (data > root->data)
           root->right = deleteNode(root->right, data);
   else
   {
        if (root->left == NULL)
           struct node *temp = root->right;
           free(root);
           return temp;
        }
        else if (root->right == NULL)
        {
           struct node *temp = root->left;
           free(root);
           return temp;
        }

        struct node* temp = minValueNode(root->right);
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
     }
     return root;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| root | 500 - 503 | 10100 |
| data | 504 -507 | 7 |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

```
...
  printf("\nDelete 7\n");
  root = deleteNode(root, 7);
 ...
```




**BSTDelete.c**

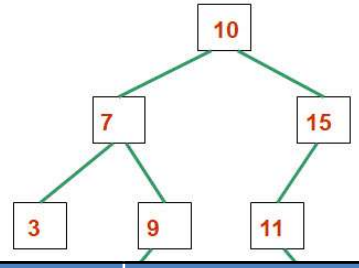
```
/* Given a binary search tree and a data, this function deletes the data
and returns the new root */
struct node* deleteNode(struct node* root, int data)
{
    if (root == NULL) return root;

    if (data < root->data)
        root->left = deleteNode(root->left, data);
    else if (data > root->data)
            root->right = deleteNode(root->right, data);
    else
    {
        if (root->left == NULL)
            struct node *temp = root->right;
            free(root);
            return temp;
        }
        else if (root->right == NULL)
        {
            struct node *temp = root->left;
            free(root);
            return temp;
        }

        struct node* temp = minValueNode(root->right);
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
    }
    return root;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| root | 500 - 503 | 10100 |
| data | 504 -507 | 7 |
| root | 600 - 603 | 1230 |
| data | 604 - 607 | 7 |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

```
...
  printf("\nDelete 7\n");
  root = deleteNode(root, 7);
 ...
```




**BSTDelete.c**

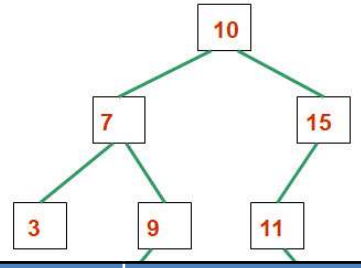
```
/* Given a binary search tree and a data, this function deletes the data
and returns the new root */
struct node* deleteNode(struct node* root, int data)
{
    if (root == NULL) return root;

    if (data < root->data)
        root->left = deleteNode(root->left, data);
    else if (data > root->data)
            root->right = deleteNode(root->right, data);
    else
    {
        if (root->left == NULL)
            struct node *temp = root->right;
            free(root);
            return temp;
        }
        else if (root->right == NULL)
        {
            struct node *temp = root->left;
            free(root);
            return temp;
        }

        struct node* temp = minValueNode(root->right);
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
    }
    return root;
}
```

| Label | Address | Value |
|---|---|---|
| root | 400 - 403 | 1010 |
| root | 500 - 503 | 10100 |
| data | 504 -507 | 7 |
| root | 600 - 603 | 1230 |
| data | 604 - 607 | 7 |
| data | 1010 - 1013 | 10 |
| left | 1014 - 1017 | 1230 |
| right | 1018 - 1021 | 1750 |
| data | 1230 – 1233 | 7 |
| left | 1234 - 1237 | 1850 |
| right | 1238 – 1241 | 1420 |
| data | 1420 – 1423 | 9 |
| left | 1424 - 1427 | 1980 |
| right | 1428 – 1431 | NULL |
| data | 1750 – 1753 | 15 |
| left | 1754 - 1757 | 2170 |
| right | 1758 – 1761 | NULL |
| | | |

```
...
  printf("\nDelete 7\n");
  root = deleteNode(root, 7);
 ...
```




**BSTDelete.c**

```
/* Given a binary search tree and a data, this function deletes the data
and returns the new root */
struct node* deleteNode(struct node* root, int data)
{
    if (root == NULL) return root;

    if (data < root->data)
        root->left = deleteNode(root->left, data);
    else if (data > root->data)
            root->right = deleteNode(root->right, data);
    else
    {
          if (root->left == NULL)
             struct node *temp = root->right;
             free(root);
             return temp;
          }
          else if (root->right == NULL)
          {
             struct node *temp = root->left;
             free(root);
             return temp;
          }

          struct node* temp = minValueNode(root->right);
          root->data = temp->data;
          root->right = deleteNode(root->right, temp->data);
      }
     return root;
}
```

| Label | Address | Value |
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| right | 1758 – 1761 | NULL |
| | | |

```
/* Given a non-empty binary search tree, return the node with minimum
data value found in that tree. Note t                ntire tree does not
need to be searched. */
struct node * minValueNode(struct node* node)
{
            struct node* current = node;

            /* loop down to find the leftmost leaf */
            while (current && current->left != NULL)
                        current = current->left;

            return current;
}
```

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```
/
a
s
{
    if (root == NULL) return root;

    if (data < root->data)
        root->left = deleteNode(root->left, data);
    else if (data > root->data)
            root->right = deleteNode(root->right, data);
    else
    {
          if (root->left == NULL)
             struct node *temp = root->right;
             free(root);
             return temp;
          }
          else if (root->right == NULL)
          {
             struct node *temp = root->left;
             free(r
             return
          }

          struct node* temp = minValueNode(root->right);
          root->data = temp->data;
          root->right = deleteNode(root->right, temp->data);
      }
      return root;
}
```

1980

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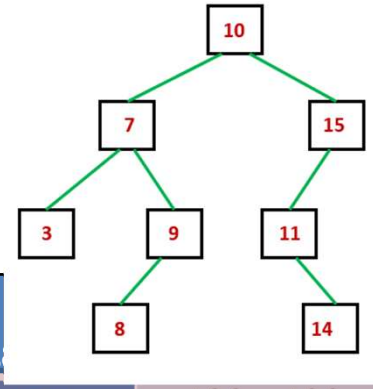


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...
  printf("\nDelete 7\n");
  root = deleteNode(root, 7);
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**BSTDelete.c**

```
/* Given a binary search tree and a data, this function deletes the data
and returns the new root */
struct node* deleteNode(struct node* root, int data)
{
   if (root == NULL) return root;

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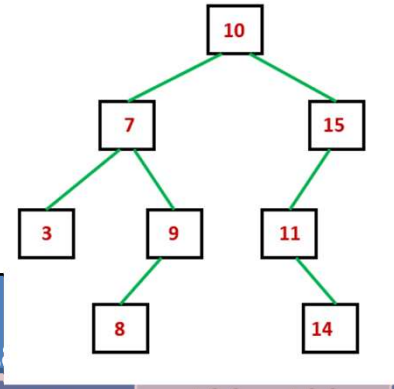
   else if (data > root->data)
           root->right = deleteNode(root->right, data);
   else
   {
        if (root->left == NULL)
           struct node *temp = root->right;
           free(root);
           return temp;
        }
        else if (root->right == NULL)
        {
           struct node *temp = root->left;
           free(root);
           return temp;
        }

        struct node* temp = minValueNode(root->right);
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
     }
     return root;
}
```

8

1980

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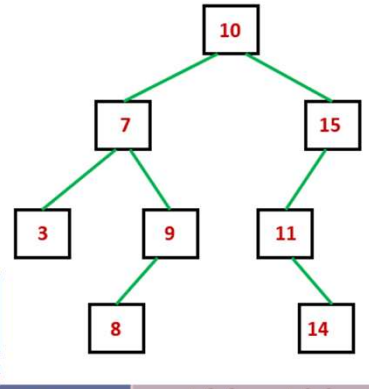
           root->right = deleteNode(root->right, data);
   else
   {
        if (root->left == NULL)
           struct node *temp = root->right;
           free(root);
           return temp;
        }
        else if (root->right == NULL)
        {
           struct node *temp = root->left;
           free(root);
           return temp;
        }

        struct node* temp = minValu          t->ri          ;
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
     }
     return root;
}
```

1420

8

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   else
   {
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           struct node *temp = root->right;
           free(root);
           return temp;
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           struct node *temp = root->left;
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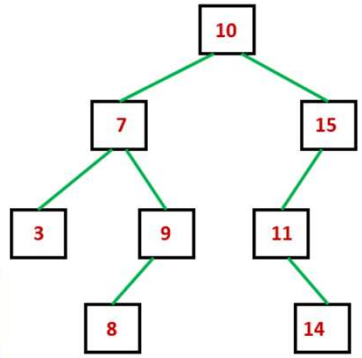
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
    }
    return root;
}
```

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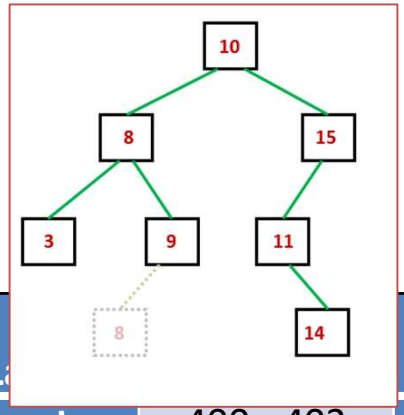
   {
        if (root->left == NULL)
           struct node *temp = root->right;
           free(root);
           return temp;
        }
        else if (root->right == NULL)
        {
           struct node *temp = root->left;
           free(root);
           return temp;
        }

        struct node* temp = minValueNode(root->right);
        root->data = temp->data;
        root->right = deleteNode(root->right, temp->data);
     }
     return root;
}
```

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| | | |

# Trees in C

**END OF PART 6**
**END OF TREES in C**