CONFIDENTIAL

C Programming Basic – week 8

Gdb – Make

Tree

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Topics of this week

- How to use debugger tool(gdb)
- Tree data structure
  - Binary Tree
  - Binary Search Tree
- Recursive processing on Tree

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`gdb` for debugging (1)

- `gdb`: the Gnu DeBugger
- http://www.cs.caltech.edu/courses/cs11/material/c/mike/misc/gdb.html
- Use when program core dumps
- or when want to walk through execution of program line-by-line

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`gdb` for debugging (2)

- Before using `gdb`:
  - Must compile C code with additional flag: `-g`
  - This puts all the source code into the binary executable
- Then can execute as: `gdb myprogram`
- Brings up an interpreted environment

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gdb for debugging (3)

```
gdb> run
```

- Program runs...
- If all is well, program exits successfully, returning you to prompt
- If there is (*e.g.*) a core dump, `gdb` will tell you and abort the program

gdb – basic commands (1)

- Stack backtrace ("`where`")
  - Your program core dumps
  - Where was the last line in the program that was executed before the core dump?
  - That's what the `where` command tells you

gdb – basic commands (2)

last call

last call in your code

```
gdb> where
#0  0x4006cb26 in free () from /lib/libc.so.6
#1  0x4006ca0d in free () from /lib/libc.so.6
#2  0x8048951 in board_updater (array=0x8049bd0,
    ncells=2) at 1dCA2.c:148
#3  0x80486be in main (argc=3, argv=0xbffff7b4) at
    1dCA2.c:44
#4  0x40035a52 in __libc_start_main () from
    /lib/libc.so.6
```

stack backtrace

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gdb – basic commands (3)

- Look for topmost location in stack backtrace that corresponds to your code
- Watch out for
  - freeing memory you didn't allocate
  - accessing arrays beyond their maximum elements
  - dereferencing pointers that don't point to part of a `malloc()`ed block

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gdb – basic commands (4)

- **`break`**, **`continue`**, **`next`**, **`step`** commands
- **`break`** causes execution to stop on a given line

  ```
  gdb> break foo.c: 100
  ```
  (setting a breakpoint)
- **`continue`** resumes execution from that point
- **`next`** executes the next line, then stops
- **`step`** executes the next statement
  - goes into functions if necessary (**`next`** doesn't)

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gdb – basic commands (5)

- **`print`** and **`display`** commands
- **`print`** prints the value of any program expression

  ```
  gdb> print i
  $1 = 100
  ```
- **`display`** prints a particular value every time execution stops

  ```
  gdb> display i
  ```

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gdb – printing arrays (1)

- `print` will print arrays as well

```
int arr[] = { 1, 2, 3 };

gdb> print arr
$1 = {1, 2, 3}
```

- N.B. the `$1` is just a name for the result

```
print $1
$2 = {1, 2, 3}
```

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gdb – printing arrays (2)

- `print` has problems with dynamically-allocated arrays

```
int *arr;
arr = (int *)malloc(3 * sizeof(int));
arr[0] = 1; arr[1] = 2; arr[2] = 3;
gdb> print arr
$1 = (int *) 0x8094610
```

- Not very useful…

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gdb – printing arrays (3)

- Can print this array by using @ (gdb special syntax)

```
int *arr;
arr = (int *)malloc(3 * sizeof(int));
arr[0] = 1; arr[1] = 2; arr[2] = 3;

gdb> print *arr@3
$2 = {1, 2, 3}
```

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gdb – abbreviations

- Common **gdb** commands have abbreviations

p (same as **print**)

c (same as **continue**)

n (same as **next**)

s (same as **step**)

- More convenient to use when interactively debugging

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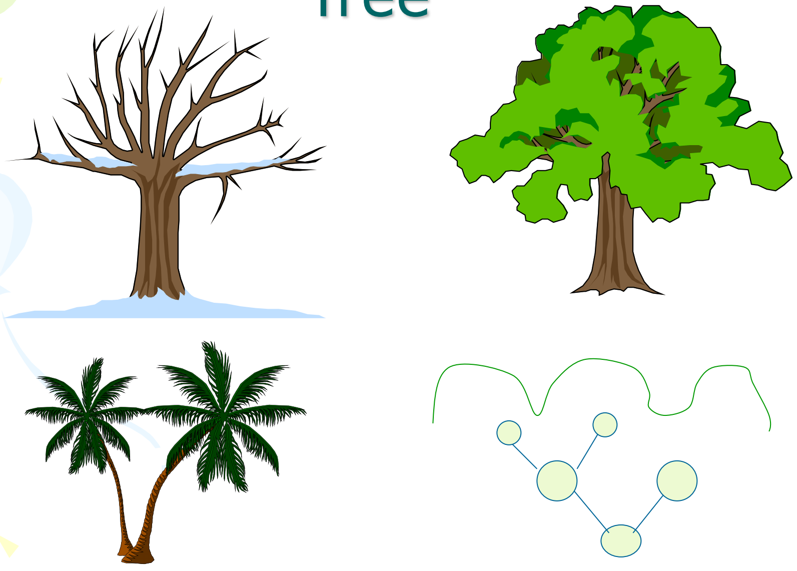
Tree



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Trees, Binary Trees, and Binary Search Trees

- Linked lists are **linear structures** and it is difficult to use them to organize a **hierarchical** representation of objects.
- Although stacks and queues reflect some hierarchy, they are limited to only **one dimension**.
- To overcome this limitation, we create a new data type called a **tree** that consists of **nodes** and **arcs**. Unlike natural trees, these trees are **depicted upside down** with the **root** at the top and the **leaves** at the bottom.

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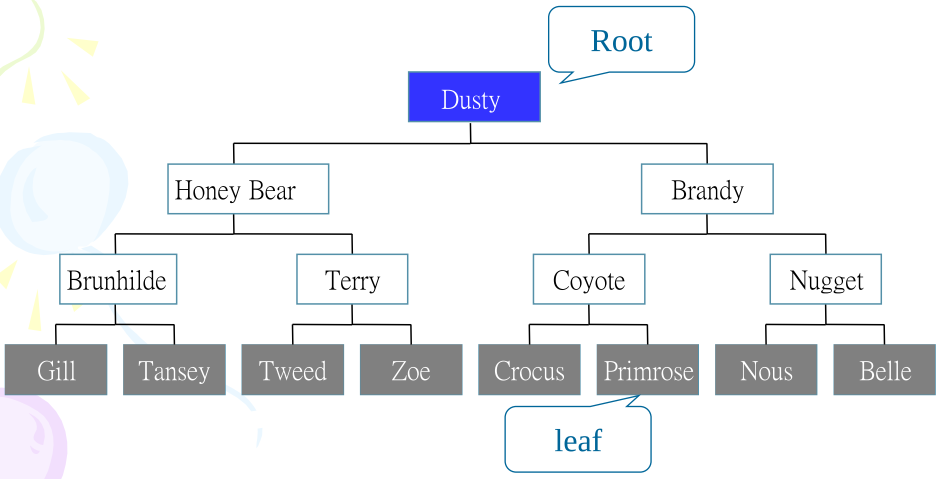
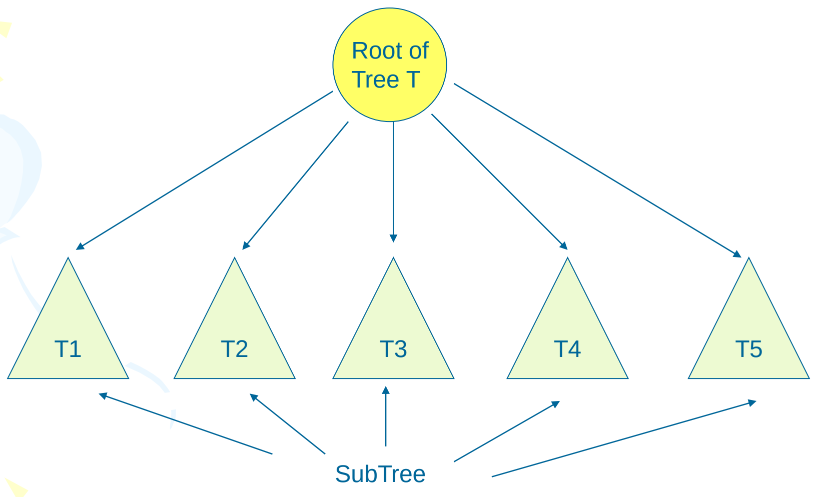
Family Tree



Definition of tree

- A tree is a finite set of one or more nodes such that:
- There is a specially designated node called the root.
- The remaining nodes are partitioned into n>=0 disjoint sets $T_1, \ldots, T_n$, where each of these sets is a tree.
- We call $T_1, \ldots, T_n$ the subtrees of the root.

Recursive definition



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Binary Tree

- A binary tree is a tree in which no node can have more than two children.
- Each node has 0, 1, or 2 children

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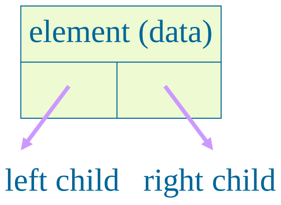
Linked Representation

- Each tree node is represented as an object whose data type is
- The space required by an n node binary tree is n * (space required by one node)

```
typedef ... elmType;
//whatever type of element
typedef struct nodeType {
    elmType element;
    struct nodeType *left, *right;
};
typedef struct nodeType *treetype;
```



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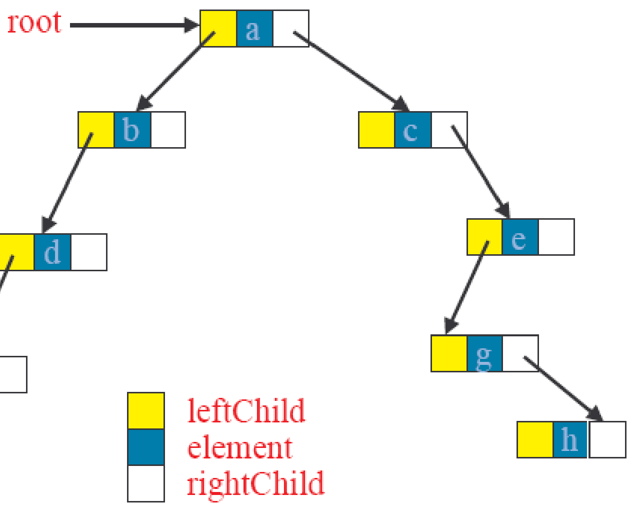
A linked binary tree



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Binary Tree ADT

- makenullTree(treetype *t)
- creatnewNode()
- isEmpty()

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Tree initialization and verification

```
typedef  …  elmType;
typedef struct nodeType {
   elmType element;
   struct nodeType *left, *right;
} node_Type;

typedef struct nodeType *treetype;

void MakeNullTree(treetype *T){
(*T)=NULL;
}
int EmptyTree(treetype T){
  return T==NULL;
}
```

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Access left and right child

```
treetype LeftChild(treetype n)
{
  if (n!=NULL) return n->left;
  else return NULL;
}
treetype RightChild(treetype n)
{
  if (n!=NULL) return n->right;
  else return NULL;
}
```

create a new node

```
node_type *create_node(elmtype NewData)
{
  N=(node_type*)malloc(sizeof(node_type));
  if (N != NULL)
  {
     N->left = NULL;
     N->right = NULL;
     N->element = NewData;
  }
  return N;
}
```

check if a node is a leaf

```
int IsLeaf(treetype n){
 if(n!=NULL)
   return(LeftChild(n)==NULL)&&(Right
   Child(n)==NULL);
  else return -1;
}
```

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Recursive processing: Number of nodes

- As tree is a recursive data structure, recursive algorithms are usefuls when they are applied on tree.

```
int nb_nodes(treetype T){
if(EmptyTree(T)) return 0;
   else return 1+nb_nodes(LeftChild(T))+
      nb_nodes(RightChild(T));
}
```

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Creat a tree from two sub-trees

```
treetype createfrom2(elmtype v,
  treetype l, treetype r){
  treetype N;
  N=(node_type*)malloc(sizeof(node_typ
  e));
  N->element=v;
  N->left=l;
  N->right=r;
   return N;
}
```

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Adding a new node to the left most position

```
treetype Add_Left(treetype *Tree, elmtype NewData){
  node_type *NewNode = Create_Node(NewData);
  if (NewNode == NULL) return (NewNode);
  if (*Tree == NULL)
      *Tree = NewNode;
  else{
      node_type *Lnode = *Tree;
      while (Lnode->left != NULL)
             Lnode = Lnode->left;
      Lnode->left = NewNode;
  }
  return (NewNode);
}
```

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Adding a new node to the right most position

```
treetype Add_Left(treetype *Tree, elmtype NewData){
  node_type *NewNode = Create_Node(NewData);
  if (NewNode == NULL) return (NewNode);
  if (*Tree == NULL)
      *Tree = NewNode;
  else{
      node_type *Rnode = *Tree;
      while (Rnode->right != NULL)
            Rnode = Lnode->right;
      Rnode->right = NewNode;
  }
  return (NewNode);
}
```

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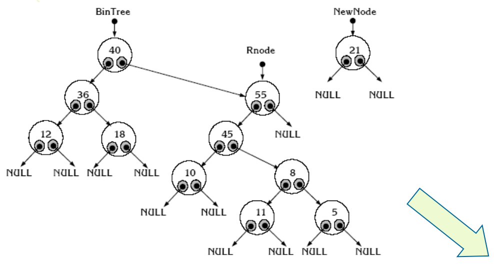
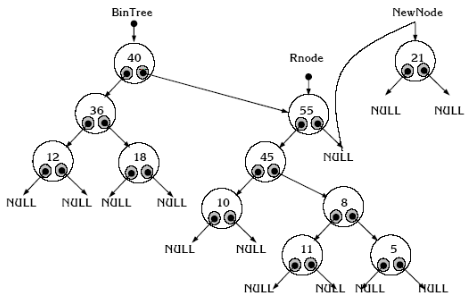
Illustration





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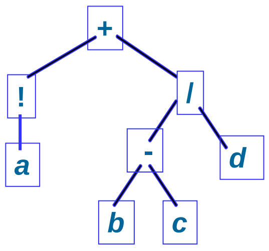
Exercise

- Develop the following helper functions for a tree:
  - return the height of a binary tree.
  - return the number of leafs
  - return the number of internal nodes
  - count the number of right children.

Exercise

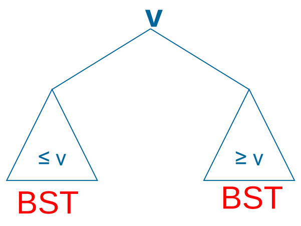
- A binary can represent an arithmetic expression: The leaves are operands and the other nodes are operators.
- The left and right subtrees of an operator node represent subexpressions that must be evaluated before applying the operator at the root of the subtree.
- For example

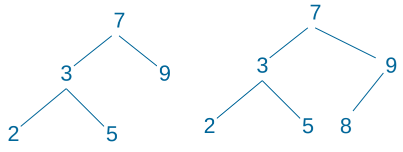
  !a + (b – c)/d
- Write a program create a tree representing this expression



Binary Search Tree

- Every element has a unique key.
- The keys in a nonempty left subtree (right subtree) are smaller (larger) than the key in the root of subtree.
- The left and right subtrees are also binary search trees.





Binary Search Tree Implementation

```
#include <stdio.h>
#include <stdlib.h>
typedef . . . KeyType; // specify a type for
  the data
typedef struct Node{
  KeyType key;
   struct Node* left,right;
   } NodeType;
typedef Node* TreeType;
```

Search on BST

```
TreeType Search(KeyType x,TreeType Root){
   if (Root == NULL) return NULL; // not found
   else if (Root->key == x) /* found x */
        return Root;
   else if (Root->key < x)
   //continue searching in the right sub tree
        return Search(x,Root->right);
   else {
   // continue searching in the left sub tree
   return Search(x,Root->left);
   }
}
```

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Insert a node from a BST

- In a binary, there are not two nodes with the same key.

```
void InsertNode(KeyType x,TreeType *Root ){
if (*Root == NULL){
    /* Create a new node for key x */
    *Root=(NodeType*)malloc(sizeof(NodeType));
    (*Root)->key = x;
    (*Root)->left = NULL;
    (*Root)->right = NULL;
}
else if (x < (*Root)->key) InsertNode(x, &(*Root)-
   >left);
else if (x> Root->key) InsertNode(x, &(*Root)-
   >right);
}
```

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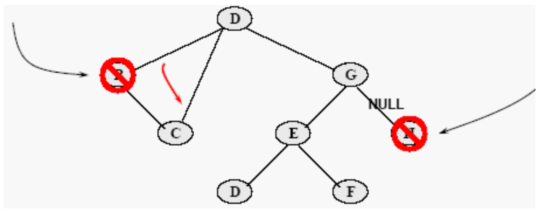
Delete a node from a BST

- Removing a leaf node is trivial, just set the relevant child pointer in the parent node to NULL.
- Removing an internal node which has only one subtree is also trivial, just set the relevant child pointer in the parent node to target the root of the subtree.



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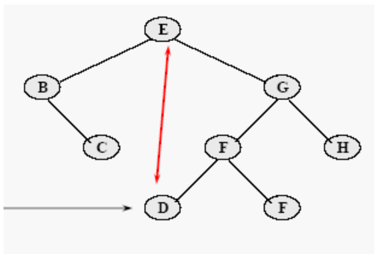
Delete a node from a BST

- Removing an internal node which has two subtrees is more complex
  - Find the left-most node of the right subtree, and then swap data values between it and the targeted node.
  - Delete the swapped value from the right subtree.



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Find the left-most node of right sub tree

- This function find the leftmost node then delete it.

```
KeyType DeleteMin (TreeType *Root ){
   KeyType k;
   if ((*Root)->left == NULL){
      k=(*Root)->key;
      (*Root) = (*Root)->right;
      return k;
   }
   else return DeleteMin(&(*Root)->left);
}
```

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Delete a node from a BST

```
void DeleteNode(key X,TreeType *Root){
   if (*Root!=NULL)
       if (x < (*Root)->Key) DeleteNode(x, &(*Root)-
   >left)
       else if (x > (*Root)->Key)
              DeleteNode(x, &(*Root)->right)
       else if
       ((*Root)->left==NULL)&&((*Root)->right==NULL)
              *Root=NULL;
       else if ((*Root)->left == NULL)
              *Root = (*Root)->right
       else if ((*Root)->right==NULL)
              *Root = (*Root)->left
       else (*Root)->Key = DeleteMin(&(*Root)->right);
}
```

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Pretty print a BST

```
void prettyprint(TreeType tree,char *prefix){
   char *prefixend=prefix+strlen(prefix);
   if (tree!=NULL){
        printf("%04d",tree->key);
        if (tree->left!=NULL) if (tree->right==NULL){
                printf("\304");strcat(prefix,"     ");
        }
        else {
                printf("\302");strcat(prefix,"\263    ");
        }
        prettyprint(tree->left,prefix);
        *prefixend='\0';
        if (tree->right!=NULL) if (tree->left!=NULL){
                printf("\n%s",prefix);printf("\300");
        } else printf("\304");
        strcat(prefix,"     ");
        prettyprint(tree->right,prefix);
   }
}
```

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Exercise

- Write a function to delete all node of a tree. This function must be called before terminating program.

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Exercise

- Create an binary search tree with 10 nodes. Each node contains an random integer.
- Ask user to input an number and search for it.
- Print the content of the trees.

Exercise

- We assume that you make a mobile phone’s address book.
- Declare a structure which can store at least "name", "telephone number", "e-mail address.”.
- Declare a structure for a binary tree which can stores the structure of an address book inside. Read data of about 10 from an input file to this binary tree as the following rules.
  - An address data which is smaller in the dictionary order for the e-mail address is stored to the left side of a node.
  - An address data which is larger in the dictionary order for the e-mail address is stored to the right side of a node.
- (1) Confirm the address data is organized in the binary tree structure with some methods (printing, debugger, etc).
- (2) Find a specified e-mail address in the binary tree and output it to a file if found.
- (3) Output all the data stored in the binary tree in ascending order for the e-mail address. (Reserve it for the next week)