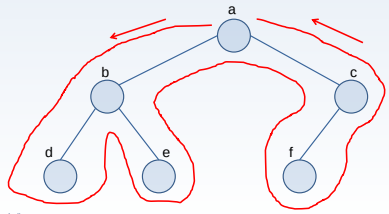
Data Structures

Trees

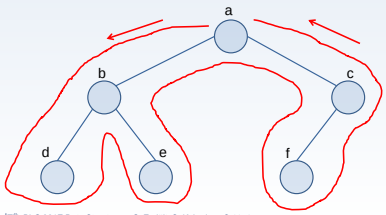
Traversal Orders

- Imagine having a string shrink-wrapped around the tree.
- If we start at the root node and follow the string around the tree, we are traversing the tree.
- In what follows, we will always go around the tree counterclockwise.



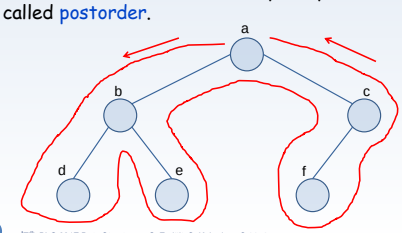
Traversal Orders

- When we traverse the tree, each node is visited three times: on the left, underneath, and on the right.
  - To picture this for nodes with one or no children, just attach imaginary children.

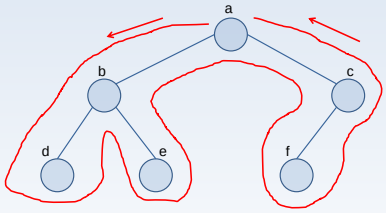


Traversal Orders

- The order of the nodes as they are passed on the left is called preorder.
- The order of the nodes as they are passed underneath is called inorder.
- The order of the nodes as they are passed on the right is called postorder.



Traversal Orders: Example



- Preorder: a b d e c f
- Inorder: d b e a f c
- Postorder: d e b f c a

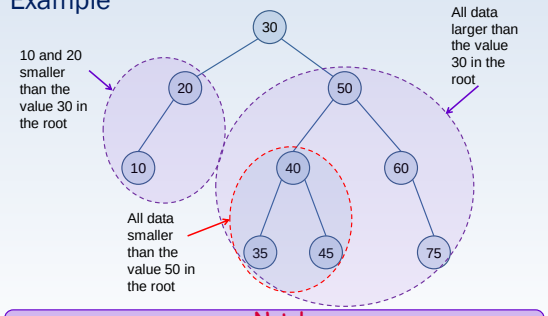
Binary Search Tree

- Trees are generally used in index structures.
- To use them for this purpose, data should be placed in the tree in a certain order.
- The simplest ordering is the binary search tree.

Rule:

- A root node
  - values in the left subtree should be smaller than the value in the root
  - values in the right subtree should be larger than the value in the root.
- The right and left subtrees of a root node have the search tree property.

Example

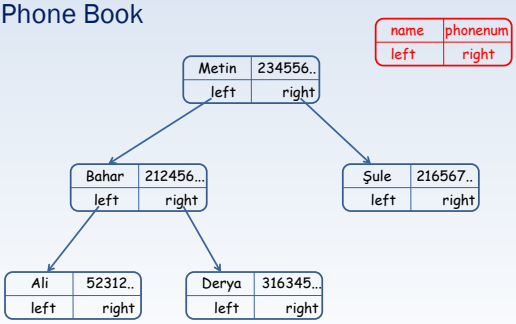


Note!
In the binary search tree, each data is located in only 1 node.

isBST(node *ptr){

```
node *t;
if(nptr==null) return true;
if(isBST(nptr->left)){ t=nptr->left;
   if(t!=null) {
         while(t->right) t=t->right;
        if(t->data>=nptr->data) return false;
   }
}
else return false;
if(isBST(nptr->right)){t=nptr->right;
   if(t!=null) {
         while(t->left) t=t->left;
        if(t->data>=nptr->data) return false;
   }
}
else return false;
return true;
}
```


Phone Book



Node Structure

```
// node.h
#define NAME_LENGTH 30
#define PHONENUM_LENGTH 15

struct Phone_node{
   char name[NAME_LENGTH];
   char phonenum[PHONENUM_LENGTH];
   Phone_node *left;
   Phone_node *right;
};
```


Node Structure

```
// tree.h
struct Tree {
  Phone_node *root;
  int nodecount;
  char *filename;
  FILE *phonebook;
  void create();
  void close();
  void emptytree(Phone_node *);
  void add(Phone_node *);
  void remove(char *);
  void remove(Phone_node **);
  void traverse_inorder(Phone_node *);
  int search(char *);
  //void update(int recordnum);
  void read_fromfile();
  void write_inorder(Phone_node *);
  void write_tofile();
};
```


Main Program

- Global definition (in phoneprog.cpp):

  ```
  typedef Tree Datastructure;
  ```

- main(), print_menu(), and perform_operation() functions do not need to change.

Constructing the Tree

```
// tree.cpp
void Tree::create() {
    root = NULL; // create empty tree
    nodecount = 0; // initialize nodecount to 0
    read_fromfile();
}
```

- We must make some changes to the function that reads the data from the file.
  - Every record read must be added to the tree in order.

Reading from File and Placing into Tree

```
// tree.cpp
void Tree::read_fromfile() {
  struct File_Record {
    char name[NAME_LENGTH];
    char phonenum[PHONENUM_LENGTH];
  };
  File_Record record;
  Phone_node *newnode;
  filename = "phonebook.txt";
  if (!(phonebook =
       fopen( filename, "r+" )))
    if (!(phonebook =
         fopen( filename, "w+" ))) {
      cerr << "Could not open file."
           << endl;
      cerr << "Will work in"
           << " memory only."
           << endl;
      return;
    }
  fseek(phonebook, 0, SEEK_SET);
  while (!feof(phonebook)) {
    newnode = new Phone_node;
    fread(&record,
          sizeof (File_Record),
          1, phonebook);
    if ( feof(phonebook) )
       break;
    strcpy(newnode->name, record.name);
    strcpy(newnode->phonenum,
                    record.phonenum);
    newnode->left = newnode->right =NULL;
    add(newnode);
    delete newnode;
  }
  fclose(phonebook);
}
```


Closing the Program

```
// tree.cpp
void Tree::close() {
   write_tofile();
   emptytree(root);
}

void Tree::write_tofile() {
  if ( !( phonebook = fopen( filename, "w+" ) ) ) {
    cerr << "Could not open file" << endl;
    return;
  }
  write_inorder(root);
  fclose(phonebook);
}
```


Write In Order

```
// tree.cpp
void Tree::write_inorder(Phone_node *p) {
  struct File_Record {
       char name[NAME_LENGTH];
       char phonenum[PHONENUM_LENGTH];
  };
  File_Record record;
  if (p) {
       write_inorder(p->left);
       strcpy(record.name, p->name);
       strcpy(record.phonenum, p->phonenum);
       fwrite(&record, sizeof(File_Record), 1,phonebook);
       write_inorder(p->right);
  }
}
```


Question

- If we write the tree to the file in order, what kind of problem would arise?
- Answer:
  - The data in the tree will be written to the file in alphabetical order.
  - When reading from the file and recreating the tree, the tree will be unbalanced.
  - The performance of the search operation in an unbalanced tree in the worst case may become the same as that in a linked list.
  - That is why implementing a "write_preorder" function instead of a "write_inorder" function will be more meaningful.

write_ preorder

```
// tree.cpp
void Tree::write_preorder(Phone_node *p) {
  struct File_Record {
       char name[NAME_LENGTH];
       char phonenum[PHONENUM_LENGTH];
  };
  File_Record record;
  if (p) {
       strcpy(record.name, p->name);
       strcpy(record.phonenum, p->phonenum);
       fwrite(&record, sizeof(File_Record), 1,phonebook);
       write_preorder(p->left);
       write_preorder(p->right);
  }
}
```

To Delete the Tree from Memory (Postorder Logic)

```
// tree.cpp
void Tree::emptytree(Phone_node *p) {
  if (p) {
    if (p->left != NULL) {
      emptytree(p->left);
      p->left = NULL;
    }
    if (p->right != NULL) {
      emptytree(p->right);
      p->right = NULL;
    }
    delete p;
  }
}
```


Searching for a Record

```
// phoneprog.cpp
void search_record() {
  char name[NAME_LENGTH];
  cout << "Please enter the name"
       << " of person you want to search for"
       << "(Press '*' for complete list):"
       << endl;
  cin.ignore(1000, '\n');
  cin.getline(name, NAME_LENGTH);
  if ( book.search(name) == 0 ) {
     cout << "Could not find record"
          << " matching search criteria" << endl;
  }
  getchar();
}
```


Searching for a Record

```
// tree.cpp
int Tree::search(char *search_name) {
  Phone_node *traverse;
  traverse = root;
  int countfound = 0;
  bool all = false;
  if (search_name[0] == '*')
       all = true;
  if (all) {
       traverse_inorder(root);
       countfound++;
  }
                              else { // single record search
                                while (traverse && !countfound) {
                                  int comparison =
                                     strcmp(search_name,traverse->name);
                                  if (comparison < 0)
                                    traverse = traverse->left;
                                  else if (comparison > 0)
                                    traverse = traverse->right;
                                  else { // if names are equal, record found
                                    cout << traverse->name << " "
                                       << traverse->phonenum << endl;
                                    countfound++;
                                  }
                                }
                              }
                              return countfound;
                            }
```


Traversing the Whole Tree

```
// tree.cpp
```

- For a printout of all data:

```
void Tree::traverse_inorder(Phone_node *p) {
   if (p){
      traverse_inorder(p->left);
      cout << p->name << " " << p->phonenum << endl;
      traverse_inorder(p->right);
   }
}
```

- At the end of this traversal, the names in the tree will be listed in alphabetical order.
- If we perform inorder traversal in the binary search tree, the data will be ordered from the smallest to the largest.

Adding a Record

```
// phoneprog.cpp
void add_record(){
  Phone_Record newrecord;
  cout << "Please enter the information for the"
       << "person you want to record" << endl;
  cout << "Name : " ;
  cin.ignore(1000, '\n');
  cin.getline(newrecord.name, NAME_LENGTH);
  cout << "Phone number :";
  cin >> setw(PHONENUM_LENGTH)
      >>newrecord.phonenum;
  book.add(&newrecord);
  cout << "Record added" << endl;
  getchar();
}
```


Adding a Record: Adding a Node to the Tree

```
// tree.cpp
void Tree::add(Phone_node *toadd) {
  Phone_node *traverse, *newnode;
  traverse = root;
  int comparison;
  bool added = false;
  newnode = new Phone_node;
  strcpy(newnode->name, toadd->name);
  strcpy(newnode->phonenum,
         toadd->phonenum);
  newnode->left = NULL;
  newnode->right = NULL;
  if (root == NULL){
       //first node being added
     root = newnode;
     nodecount++;
     return;
  }
                                  while ((traverse != NULL) && (!added)){
                                    comparison = strcmp(newnode->name,
                                                        traverse->name);
                                    if (comparison < 0) {
                                      if (traverse->left != NULL)
                                         traverse = traverse->left;
                                       else {
                                         traverse->left = newnode;
                                         added = true;
                                       }
                                    }
                                    else if (comparison > 0) {
                                      if (traverse->right != NULL)
                                         traverse = traverse->right;
                                      else {
                                         traverse->right = newnode;
                                         added = true;
                                      }
                                    }
                                    else
                                      cout << "Data cannot repeat.\n";
                                  }
                                  if (added) nodecount++;
                                }
```

Updating a Record

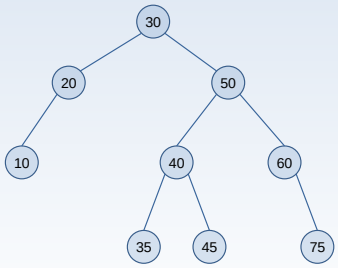
```
// phoneprog.cpp
void update_record() {
  char name[NAME_LENGTH];
  char choice;
  cout << "Please enter the name"
       << " of the person you want"
       << " to update:" << endl;
  cin.ignore(1000, '\n');
  cin.getline(name,NAME_LENGTH);

  int personcount = book.search(name);
  if (personcount == 0) {
    cout << "Could not find"
         << " record matching"
         << " criteria" << endl;
  }
  else {
     ...
  }
  getchar();
}
```

```
cout << "Record found." << endl;
cout << "Do you want to update?"
     << " (y/n) ";
do {
  cin >> choice;
} while (choice != 'y' && choice != 'n');
if (choice == 'n') return;
Phone_Record newrecord;
cout << "Please enter current info"
     << endl;
cout << "Name : " ;
cin.ignore(1000, '\n');
cin.getline(newrecord.name, NAME_LENGTH);
cout << "Phone number :";
cin >> setw(PHONENUM_LENGTH)
    >> newrecord.phonenum;
book.remove(name);
book.add(&newrecord);
cout << "Record successfully updated"
     << endl;
```


Removing a Record

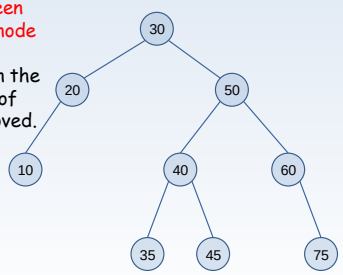
- The operation of removing from a binary search tree consists of two stages.
  - Searching for the element to be removed
  - Performing the remove operation
- Only the desired element should be removed from the tree without breaking the structure of the search tree.
- There are four cases to consider:
  - Removing a leaf
  - Removing a node that has only a left child
  - Removing a node that has only a right child
  - Removing a node that has both children

Removing a Leaf



Removing a Node that Has a Single Child

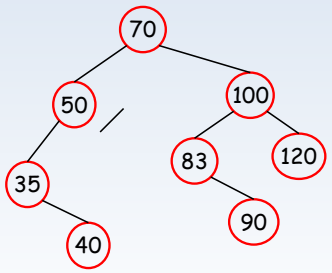
- If the node has a single child, the link between the parent and the node to be removed is established between the parent and subtree of the node to be removed.



Removing a Node That Has Both Children

- We move the right subtree to where the removed node used to be, and
- We try to link the left subtree to an approriate node in the right subtree.
  - We must link the left subtree to the left of the leftmost child of the right subtree.

Removing a Node That Has Both Children: Example



Removing a Record

```
// phoneprog.cpp
void remove_record() {
   char name[NAME_LENGTH];
   char choice;
   cout << "Please enter name of person you want to delete:" << endl;
   cin.ignore(1000, '\n');
   cin.getline(name,NAME_LENGTH);
   int personcount = book.search(name);
   if (personcount == 0) {
      cout << "Could not find record matching search criteria" << endl;
   }
   else {
      cout << "Is this the record you want to delete?(y/n)";
      do {
        cin >> choice;
      } while (choice != 'y' && choice != 'n');
      if (choice == 'n') return;
      book.remove(name);
      cout << "Record removed" <<endl;
   }
}
```


Removing a Record

```
// tree.cpp
void Tree::remove(char *remove_name){
   Phone_node *traverse, *parent;
   traverse = root;
   bool found = false;
   char direction = 'k';
   while (traverse && !found) {
      int comparison = strcmp(remove_name, traverse->name);
      if (comparison < 0) {
         parent = traverse;
         direction = 'l';
         traverse = traverse->left;
      }
      else if (comparison > 0) {
         parent = traverse;
         direction = 'r';
         traverse = traverse->right;
      }
      else // found record to remove
         found = true;
   }
   if (found) {
      ???
   }
   else
      cout << "Could not find"
           << " record to remove.\n";
}
```


Removing a Node

- There are four possible cases:
  - Removing a leaf
  - Removing a node that has only a left child
  - Removing a node that has only a right child
  - Removing a node that has both children

Removing a Leaf

```
// tree.cpp
 if (traverse->left == NULL && traverse->right == NULL) {

       switch (direction) {
             case 'l':
                 parent->left = NULL;
                 break;
             case 'r':
                 parent->right = NULL;
                 break;
             default:
                 root = NULL;
                 break;
       }
 }
 delete traverse;
```


Removing a Node That Has Only Left Child

```
// tree.cpp
   else if (traverse->right == NULL) {
     switch (direction) {
          case 'l':
             parent->left = traverse->left;
             break;
          case 'r':
             parent->right = traverse->left;
             break;
          default:
             root = traverse->left;
             break;
     }
   }
   delete traverse;
```

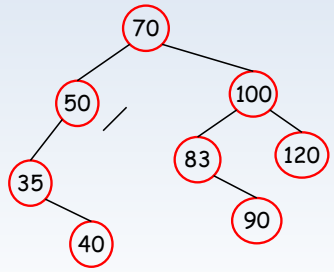

Removing a Node That Has Only Right Child

```
// tree.cpp
   else if (traverse->left == NULL) {
     switch (direction) {
          case 'l':
             parent->left = traverse->right;
             break;
          case 'r':
             parent->right = traverse->right;
             break;
          default:
             root = traverse->right;
             break;
     }
   }
   delete traverse;
```

Removing a Node That Has Both Children

```
// tree.cpp
    else {
      Phone_node *q = traverse->right;
      while ( q->left )
           q = q->left;
      q->left = traverse->left;
      switch (direction) {
           case 'l':
              parent->left = traverse->right;
              break;
           case 'r':
              parent->right = traverse->right;
              break;
           default:
              root = traverse->right;
              break;
      }
    }
    delete traverse;
```


Example



Removing a Record

```
// tree.cpp
void Tree::remove(char *remove_name) {
   Phone_node *traverse, *parent;
   traverse = root;
   bool found = false;
   char direction = 'k';
   while (traverse && !found) {
      int comparison = strcmp(remove_name, traverse->name);
      if (comparison < 0) {
         parent = traverse;
         direction = 'l';
         traverse = traverse->left;
      }
      else if (comparison > 0) {
         parent = traverse;
         direction = 'r';
         traverse = traverse->right;
      }
      else // found record to remove
         found = true;
   }
                                    if (found){
                                       ???
                                    }
                                    else
                                       cout << "Could not find"
                                            << " record to remove.\n";
                                    }
```


Removing a Record

```
// tree.cpp
void Tree::remove(char *remove_name) {
   Phone_node *traverse, *parent;
   traverse = root;
   bool found = false;
   char direction = 'k';
   while (traverse && !found) {
      int comparison = strcmp(remove_name, traverse->name);
      if (comparison < 0) {
         parent = traverse;
         direction = 'l';
         traverse = traverse->left;
      }
      else if (comparison > 0) {
         parent = traverse;
         direction = 'r';
         traverse = traverse->right;
      }
      else // found record to remove
         found = true;
   }
                                    if (found){
                                       if (direction == 'l')
                                          remove(&parent->left);
                                       else if(direction == 'r')
                                          remove(&parent->right);
                                       else  remove(&root);
                                    }
                                    else
                                       cout << "Could not find"
                                            << " record to remove.\n";
                                    }
```


Removing a Record

```
// tree.cpp
void Tree::remove(Phone_node **p) {
  Phone_node *r, *q;  // used to find place for left subtree
  r = *p;
  if (r == NULL) // attempt to delete nonexistent node
       return;
  else if (r->right == NULL) {
       *p = r->left; // reattach left subtree
       delete r;
  }
  else if (r->left == NULL) {
       *p = r->right; // reattach right subtree
       delete r;
  }
  else {  // neither subtree is empty
       for (q = r->right; q->left; q = q->left); // inorder successor
       q->left = r->left; // reattach left subtree
       *p = r->right;     // reattach right subtree
       delete r;
  }
}
```

p → pointer that will change
r → traverse

Practice

- If every person has more than one phone number
  - Add a linked list head pointer to the phonenum field of each node.