OO Programming

- Information Hiding – ability to maintain control over private variables
- Data Abstraction – (use of information hiding) Internal representation plus a set of procedure to access and manipulate the data
- Dynamic Binding – defers operation control to run–time — decision making based on state of an object (polymorphism)
- Inheritance – structure of ADTs within a hierarchy (single inheritance) or network (multiple inheritance)

An Example of Using Inheritance

- We have learned several types of trees, such as binary trees, binary search trees, AVL trees, and heaps.
- We have learned various operations to manipulate trees, such as, traversals, insertion, and deletion.

Question: Do we have to implement four separate binary tree classes ?

Several Observations

- In/pre/post order traversal methods will be identical for binary trees, binary search tree, and AVL tree classes.
- Insertion is not clearly defined for binary trees in general, but is well-understood for binary search trees, AVL trees, and heaps, although the methods of insertion are different among these tree types.
- The same observation applies to the deletion operation.

If we implement 4 different tree classes, there will be significant redundancy in coding (consider 4 identical implementations of the preorder traversal).

However, there *are* four types of trees! What is the way out ?

Inheritance

```
template <class T>
struct Binary_node {T data; Binary_node* left,right;};

template <class T>
class Binary_tree {
  public:
    Binary_tree();  ~Binary_tree();
    void inorder();
    void preorder();
    void postorder();
    bool search(T& entry);     // How ?
    T& find_max ();
  protected:
    Binary_node* root;
    ... auxiliary functions omitted ...
};
```

```
template <class T>
class Search_tree : public Binary_tree {
  public:
   Search_tree();   ~Search_tree();
   bool search (T& entry);
   void insert (T& entry);
   void remove (T& target);
   T& find_max ();
  protected:
    ... auxiliary functions omitted ...
};
```


- Class `Search_tree` is said to be **derived** from class `Binary_trees`
  - ☞ `Binary_tree` is called the **base/parent** class.
  - ☞ `Search_tree` is called the **derived/child** class.
- `Search_tree` **inherits** all the resources of its base class.
  - ☞ In/pre/post order traversals and the tree assignment operators are automatically available to `Search_tree`
- `Search_tree` **overrides** the `search()` and `find_max()` methods of its base class.
- `Search_tree` also provides capabilities not provided by its base class, namely the `insert()` and `remove()` methods.

- By default, public members of the base class can only be used by member functions of the derived class (inaccessible to users of derived class).
- The keyword **public** is used to make those functions available to users of the new class.
- Private members of a base class, public or not, cannot be accessed by derived classes.
- **Protected** members of a base class can be accessed by derived classes, but not others.

Deriving AVL Trees

```
template <class T>
class AVL_node : public Binary_node
{ balance_factor balance; };

template <class T>
class AVL_tree : public Search_tree {
  public:
   AVL_tree();  ~AVL_tree();
   void insert (T& entry);
   void remove (T& target);
  protected:
    ... auxiliary functions omitted ...
};
```

Discussion

- AVL_tree inherits all the resources of Search_tree and Binary_tree.
- AVL_tree overrides the insert() and remove() methods of Search_tree.
- Note that AVL_tree inherits root, which originates from Binary_tree and is of type Binary_node*.
- This is fine because in C++ a pointer to a base class can point to an object of derived classes — this feature is called **polymorphism**.

A Dilemma

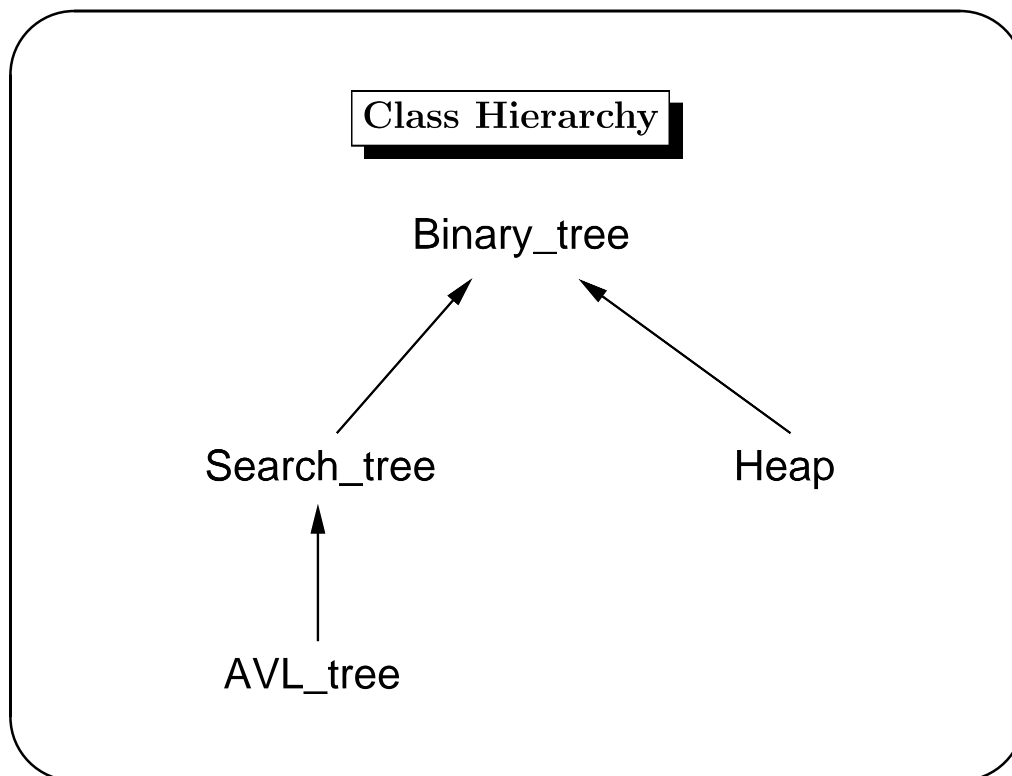
Do we want to derive class Heap from Binary_tree ?

Pro: At least conceptually, heaps are (complete) binary trees. They do have the same set of functionalities provided by the Binary_tree class.

Con: The array representation of heaps is so different from that of general binary trees that *all* inherited resources need to be overridden.

- There are no right or wrong answers to this problem. Just tradeoffs.
- For the purpose of discussion, let us derive Heap from Binary_tree.

```
template <class T>
class Heap : public Binary_tree {
  public:
    Heap();  ~Heap();
    void inorder();
    void preorder();
    void postorder();
    bool search(T& entry);
    T& find_max ();
  protected:
    ... auxiliary stuffs omitted here ...
};
```

How Resources are Shared in The Hierarchy

	BT	BST	AVL	Heap
traversals	by itself	from BT	from BT	by itself
search	by itself	by itself	from BST	by itself
insert	NA	by itself	by itself	by itself
remove	NA	by itself	by itself	by itself
assignment	by itself	from BT	from BT	by itself
find_max	by itself	by itself	from BST	by itself

Polymorphism

To treat objects of a derived class as objects of the base class.

```
class X {int a, b;};
class Y : public X  {int c;};

main ()
{
  X x, *x_ptr=&x;
  Y y, *y_ptr=&y;
  x = y;           // illegal
  y = x;           // illegal
  x_ptr = &y;      // legal;
  y_ptr = &x;      // illegal
  x_ptr = y_ptr;  // legal
  y_ptr = x_ptr;  // illegal
}
```

Discussion

- If class `Y` is derived from class `X`, an object of `Y` should be considered to be of type `X`.
  - ☞ Since `Search_tree` is a derived class of `Binary_tree`, a binary search tree is also a binary tree.
- However, when a child object is stored in a variable of the parent class, extended capabilities/resources are not copied.
  - ☞ Statement "`x=y;`" will not copy `y.c` to `x`.
- A pointer to a base class can point to an object of the derived class.
  - ☞ A `Binary_tree*` can point to a `Search_tree`.
  - ☞ In our example, `x_ptr = &y` is legal.
    So is `x_ptr = y_ptr`.

A Second Example

```
main()
{
  Binary_tree<int> bt, *bt_ptr;
  Search_tree<int> bst, *bst_ptr;
  heap<int> hp, *hp_ptr;
  AVL_tree<int> avl, *avl_ptr;

  bt = bst;              bt_ptr = &bst;
  bt = hp;               bt_ptr = hp_ptr;
  bst = hp;              bst_ptr = &hp;
  bst = avl;             bst_ptr = avl_ptr;

  bst_ptr = bt_ptr;
  avl_ptr = bst_ptr;
  hp_ptr  = avl_ptr;
}
```

Wait a Minute ...

- Assume that `avl` is a correct AVL tree.
- Let `bst_ptr = &avl`;
- **Question:** Is the result of `bst_ptr->insert(30);` a correct AVL tree ?

  ☞ Why ?
- Solution ?

Virtual Functions

```
template<class T>
class Binary_tree {
...
virtual void insert (T& x);
virtual void remove (T& x);
virtual bool find   (T& x);
void inorder ();
...
};

template<class T>
class Search_tree : public Binary_tree {
...
void insert (T& x);
void remove (T& x);
bool find (T& x);
```

```
...
};

template<class T>
class AVL : public Search_tree {
...
void insert (T& x);
void remove (T& x);
...
};

main()
{
  Binary_tree<int> bt, *bt_ptr;
  Search_tree<int> bst, *bst_ptr;
  AVL<int> avl, *avl_ptr;

  ... construct trees bt, bst, hp, and avl ...
```



```
  bt_ptr = &bt;
  bt_ptr->insert(30);  // the insert() of BT
  bt_ptr->find(30);    // the find() of BT
  bt_ptr->inorder();    // the inorder() of BT

  bt_ptr = &bst;
  bt_ptr->insert(30);  // the insert() of BST
  bt_ptr->find(30);    // the find() of BST
  bt_ptr->inorder();    // the inorder() of BT

  bt_ptr = &avl;
  bt_ptr->insert(30);  // the insert() of AVL
  bt_ptr->find(30);    // the find() of BST
  bt_ptr->inorder();    // the inorder() of BT
}
```

An Exercise

```
class A {
public:
  int x;
  A () {x = 1;}
  void f () {x += 1;}
  void g () {x += 10;}
  virtual void h () {x += 100;}
};

class B : public A {
public:
  void g () {x += 100;}
  void h () {x += 1000;}
};
```



```
main ()
{
  A a, *a_ptr = &a;
  B b, *b_ptr = &b;

  a_ptr->f();  a_ptr->g();  a_ptr->h();
  cout << a_ptr->x;

  b_ptr->f();  b_ptr->g();  b_ptr->h();
  cout << b_ptr->x;

  a_ptr = &b;
  a_ptr->f();  a_ptr->g();  a_ptr->h();
  cout << a_ptr->x;
}
```

Abstract Classes

Let us consider class `Binary_tree` again.

- We cannot insert anything to a `Binary_tree` and to remove anything from the tree.
- It makes no sense to actually create a `Binary_tree` object.
- However, the existence of the `Binary_tree` class makes sense.
  1. It defines the common features of all types of binary trees.
  2. It provides a place to implement tree traversals, to be inherited by derived binary trees.
- The solution is to define `Binary_tree` as an abstract class.


```
template <class T>
class Binary_tree {
  public:
    Binary_tree();  ~Binary_tree();
    void inorder();
    void preorder();
    void postorder();
    Binary_tree& operator= (Binary_tree&);

    virtual bool search (T& entry);
    virtual void insert (T& entry) = 0;
    virtual void remove (T& entry) = 0;
  private:
    ... We don't care about private part here ...
}
```

- A virtual function that ends with `=0` is called a **pure** virtual function, meaning that you are not to provide implementation for the function.
- A class that has at least one pure virtual function is called an **abstract class**.
- You cannot initiate any object of an abstract class.
  - ☞ "`Binary_tree g;`" is illegal with the new `Binary_tree` definition.
  - ☞ "`Binary_tree *g = new Binary_tree;`" is also illegal.
- However, "`Binary_tree *g = new AVL_tree`" is legal, because an abstract class pointer can point to objects of its derived classes.