CS 162
Intro to Computer Science II

Lecture 17

Implement inheritance

Begin Polymorphism

2/26/24

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I can't count the amount of times I've been stuck on a frustrating coding problem for hours - only to come back with a clear mind the next day and solve it in minutes.

Sleep is the best debugger 🔥

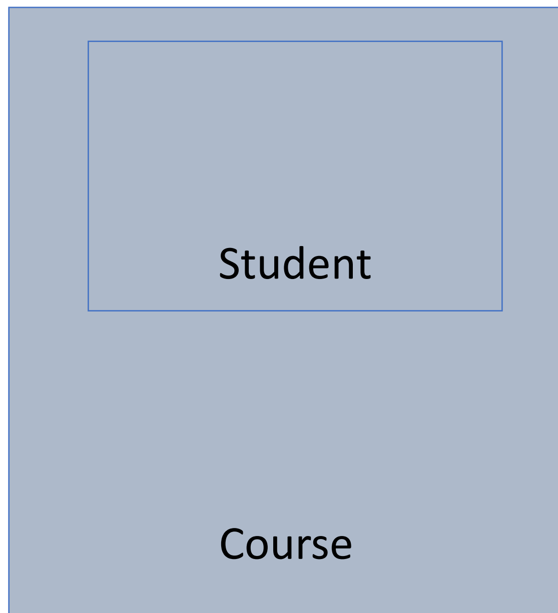
4:37 PM · 07 Apr 22 · FeedHive.io

Odds and Ends

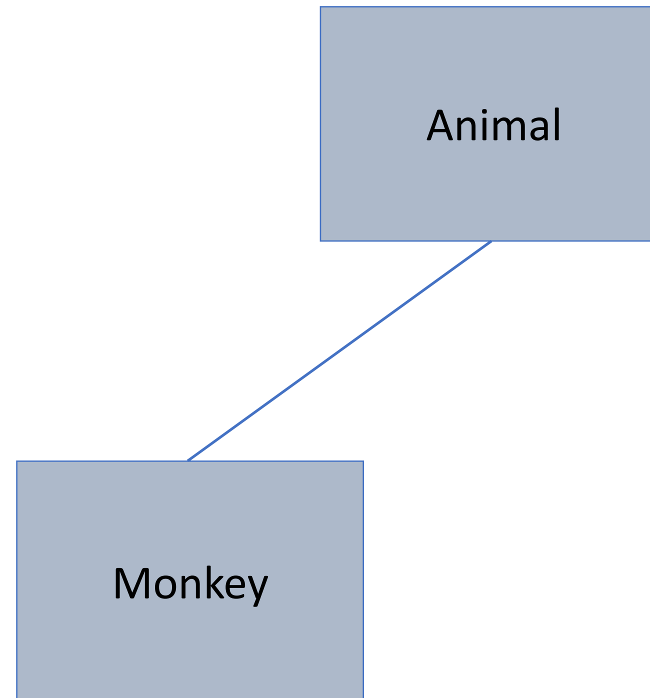
- Assignment 3 due extension:
  - Now due: Tuesday 2/27 11:59 pm
  - Demo due: Friday of Week 10 3/15
- Lab 8, WS8 posted

Inheritance vs. Composition

- Composition
  - Course "has a" Student



- Inheritance
  – Monkey "is a" Animal



Define Inheritance

- Parent class declared and defined as normal
- Child class:
  - class Derived:public Base {};
    - i.e. `class Monkey : public Animal {};`
  - List only member variables you want to add, not what is inherited
  - Only redeclare inherited member functions if you want to redefine them
    - When an inherited member function definition is changed in the derived class

- Derived classes can be used anywhere the base class would be used, but not the other way around
  - i.e. anywhere you use the Animal, you can use the Monkey, but not everywhere you use the Monkey can you use the Animal

These things are NOT Inherited:

- Base class constructor
  - Though it can be called from the derived class
  - `Child::Child():Parent(){}`
  - Base is called first to initialize all of the base member variables
  - If base constructor is not specified, the base default constructor will be used
- Copy Constructor
- Assignment Operator Overload
- Destructor

Interface (.h)

- Declare the Parent as normal
- The Child:

```
class Child : public Parent {
      private:
            //any members which are unique to the child
      public:
            Child(); //default constructor
            //other members including redefined functions from Parent
};
```

Implementation (.cpp)

- Parent class defined as normal
- Child:

```
Child::Child():Parent() {//child makes call to parent constructor first
              //initialize the member variables that are unique to child
}
//define all other member functions as normal
//redefining of parent functions follows the normal way of defining
functions
```

Inheritance with the Big 3

- Recall: Big 3 are needed whenever there is dynamic memory or pointers, they are not inherited from the parent. To use in child successfully, they must be defined correctly in parent.

```
Child& Child::operator = (const Child& other) {
        Parent::operator = (other); //invoke parent class AOO
        //continue with things unique to child
}

Child::Child(const Child& copy):Parent(copy) {
        //continue with things unique to child
}

Child::~Child() {
        //define as normal, parent's will be automatically called after the child's completes
        //destructors go in the reverse of constructors calls
}
```

Inherited but Restricted

- Private member variables are inherited but cannot be accessed by name
  - Need to use accessor and mutator functions
- Private member functions are inherited but cannot be accessed by the derived class

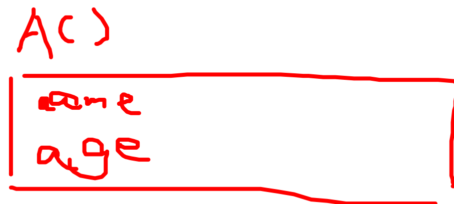
- Recalled that we've seen two access specifiers:
  - `private, public`
- Now the 3rd one: **`protected`**
  - Allows for the derived class to be able to access things directly by name
  - Every other class would view them as private

Public vs. Private vs. Protected

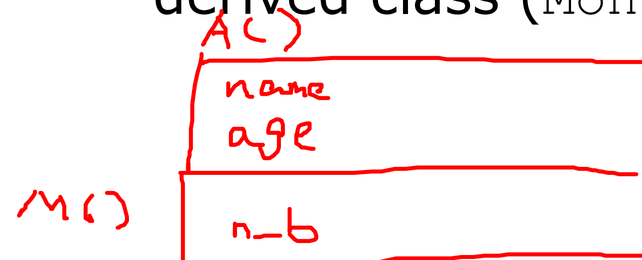
- Anything public in the parent is public to the child
- Anything private in the parent is private to the child
  - This means the child cannot use private parent functions
  - This means the child cannot use private member variables of parent by name, have to use the inherited accessor and mutator functions
- Anything protected in the parent is public to the child but private to everyone else
  - This means the child can use protected member variables and functions of parent by name

Creation

- Base class Object:
  - i.e. Creating an Animal object: `Animal a1;`
  - `Animal` constructor is invoked, memory allocated for the base class

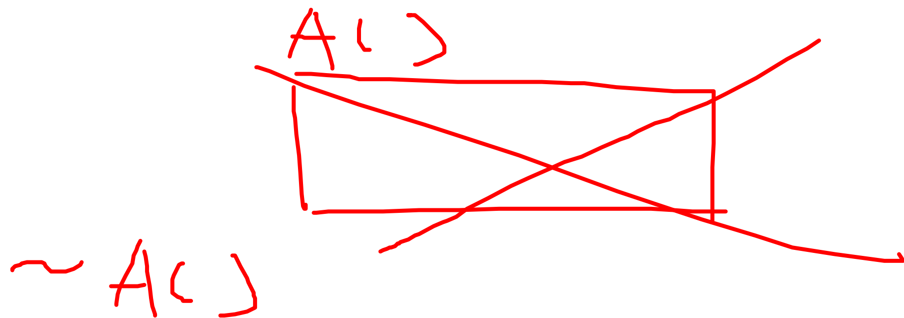


- Child class Object:
  - i.e. Creating an Monkey object: `Monkey m1;`
  - First, the `Animal` constructor is invoked, then the `Monkey` constructor invoked
  - memory allocated with enough space for the base class (`Animal`) and the derived class (`Monkey`)

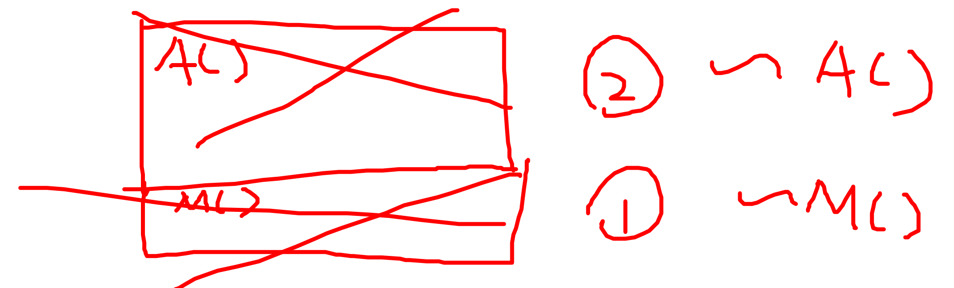


Deletion

- Base Class Object:
  - i.e. Delete an Animal object: `a1;`
  - `Animal` destructor is invoked, memory deallocated for the base class



- Child Class Object:
  - i.e. Deleting an Monkey object: `m1;`
  - First, the `Monkey` destructor is invoked, then the `Animal` destructor invoked
  - **Note: Deletion has reverse order of creation**



More on Access Control

- Protected
  - `protected` in the parent is `public` to the child but `private` to everyone else

- Using protected access is a double-edged sword:
  - It can make it easier to implement classes by avoiding writing a public interface for some members.
  - *But*, it makes your derived classes vulnerable to changes to the protected members of the base class
    - Using a public interface can insulate you from the need to make changes in the derived classes.

More on Access Control

- Recall:
  - `class Monkey : public Animal { ... };`
  - This means that we used public inheritance.

- Use public inheritance to implement a true “is-a” relationship between objects

More on Access Control

- Public inheritance
  - private members of the base class are inaccessible in the derived class; protected members remain protected; and public members remain public
- Protected inheritance
  - private members of the base class are inaccessible in the derived class; protected members remain protected; **but public members become protected**
- Private inheritance
  - private members of the base class are inaccessible in the derived class; **protected and public members become private**

C++ Upcasting and Downcasting

- Upcasting and downcasting gives a possibility to build complicated programs with a simple syntax. It can be achieved by using Polymorphism (later).
- Upcasting: treat a derived type (child) as its base type (parent)
  - Always allowed in public inheritance
  - i.e. assign a child to parent, `Animal a = m; // m is a Monkey object`
- Downcasting: treat a base type (parent) as its derived type (child)
  - Not always allowed, need to manually assigned
  - i.e. assign a parent to child, `Monkey m = a; //this gives you an error`
- In short, use upcasting often
  - To help you memorize, “A child can become a parent, but a parent cannot become a child again.”

Polymorphism

- Polymorphism – the condition of having many forms
- It allows us to treat an object of one class as an object of a different class, typically where the two classes are related by inheritance
- Why we need polymorphism? Consider this…
- Classes structure:
  - `Monkey`, `Sea_Otter`, and `Sloth` are derived from `Animal`

Polymorphism

- Write a program to allow someone to work with animals
  - The animals could be one of many types: monkey, sloth, sea otter, etc.
  - The animals can be entered in any order
  - We'd like to store all of the animals in a single array, so we can work with them all at once (e.g. to let them make noise at once)
  - Still, when working with an individual animal in the array, we want that animal to exhibit all of the characteristics of its specific class, like the way they make noises

Polymorphism (objects)

- First, let's look at polymorphism by seeing what happens when we try to cast between object types:

```
Animal a1;
Monkey m1 (“monkey1”, 10, 15);
a1 = m1;
a1.display();
a1.make_noise(4);
```

- What type of casting is this? Upcasting or downcasting?
- Recall:
  - Upcasting: converting a derived class reference or pointer to a base class
  - Downcasting: converting a base class reference or pointer to a derived class

- Demo…

Polymorphism (objects)

- Note: for functions that were redefined in the `Monkey` class (i.e. the derived class), the version of the function from the `Animal` class (i.e. the base class) is used.

- When upcasting, specialized information and functions from the derived class (like the `Monkey`'s `longest_jump` and redefined `display()` and `make_noise()`) are lost.
  - The only information and functions available in the upcasted object are those that were defined in the base class to which we're casting.

Polymorphism (objects)

- What happens when we try to cast the other way (downcasting):

```
Animal a2 (“animal2”, 20);
Monkey m2 = a2;
```

- Demo…
- This doesn’t even compile…
    - Which makes sense. An `Animal` is not necessarily a `Monkey`, it can be a `Sea_Otter` or `Sloth`, too. Thus we can’t automatically cast an `Animal` object as a `Monkey` object.

Polymorphism (pointers)

- What happens when we start working with pointers:

```
Animal *a_ptr;
Monkey m3 ("monkey3", 5, 20);
a_ptr = &m3;
a_ptr->display();
a_ptr->make_noise(4);
```

- Demo…
- Same as upcasting objects above. The specialized information and functions from the derived `Monkey` class are lost.

Why it’s not working?

- The reason even the pointer here is treated as an `Animal` object is because the decision about what functions to call here are made at **compile time**
  - This is called **static binding**

- We need a better weapon to accomplish our goals…

Virtual functions

- Use **virtual functions** and **pointers** together to bypass static binding

- A virtual function is one that is declared in the base class with the `virtual` keyword

```
virtual void some_function();
```

  - This indicates to the compiler that **dynamic binding** should be used at runtime, to determine which version of the function to call based on what kind of object is being pointed to.
  - i.e.

```
Animal* a_ptr = &m1;
a_ptr->make_noise(); // make_noise() is a virtual function
```

- Demo…

More details on virtual

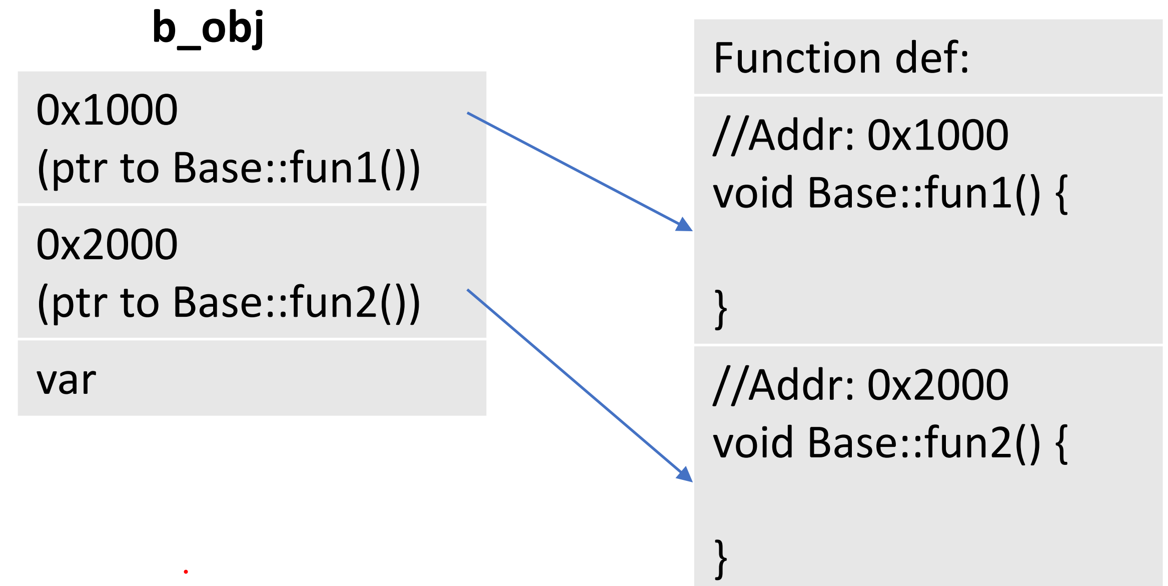
- The determination about which function to call at runtime instead of compile time:
  - When each function is called, C++ will figure out what specific class of object is being pointed to by the base class pointer (i.e. `a_ptr`)
  - Once it figures out what class of object is pointed to, it will traverse up the inheritance chain (first checking `Monkey`, then `Animal`) until it finds an implementation of the called function.
  - The first class to implement the called function in the chain will have that function called.
- This is true polymorphism: a pointer to an `Animal` object is being treated differently depending on what kind of object it actually points to.

Memory layout of virtual functions

- Let's start with a simple class:

```
class Base {
        private:
                int var;
        public:
                void fun1();
                void fun2();
};

Base b_obj;
```

- Memory Layout

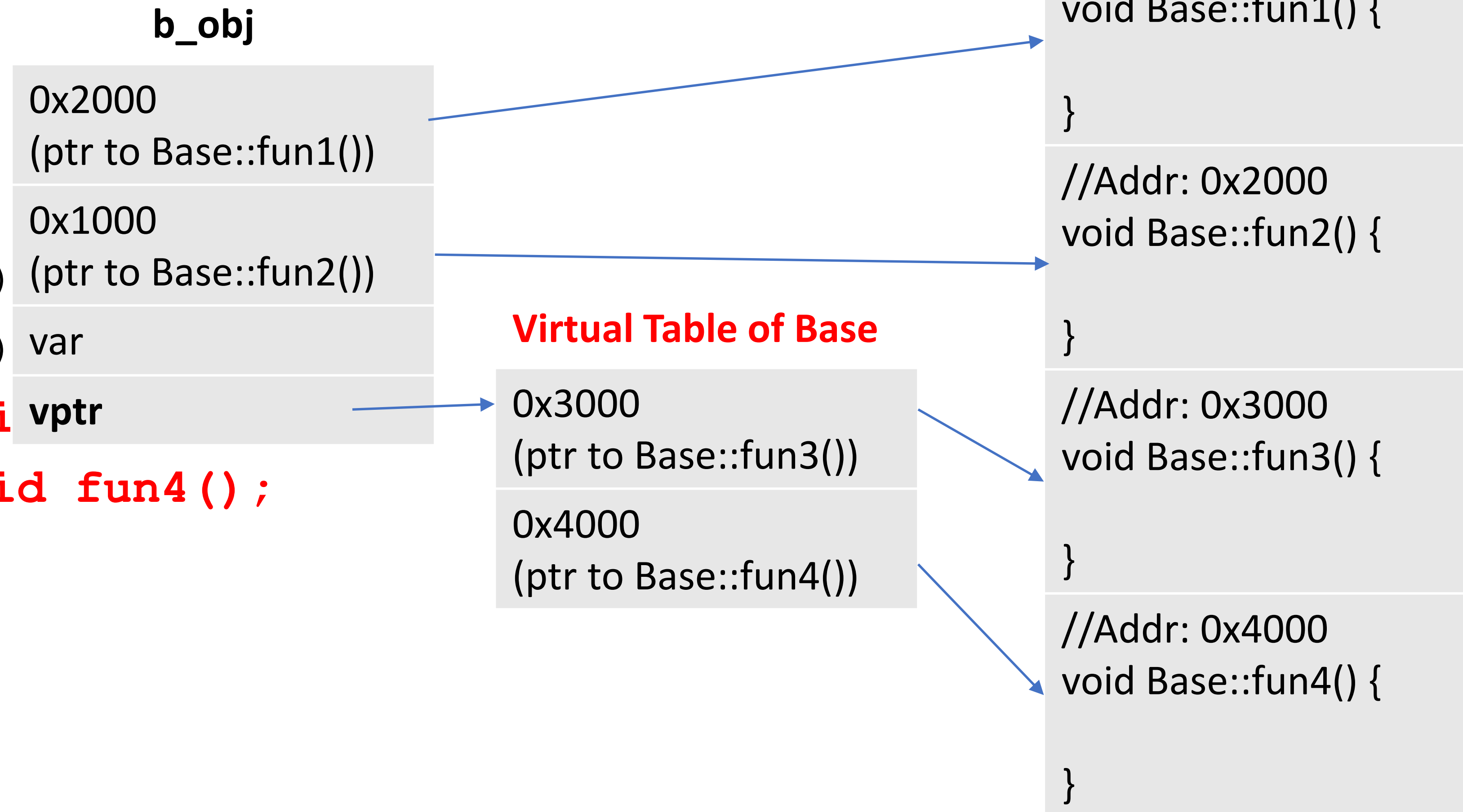


Memory layout of virtual functions

- Now, let's add two virtual func:

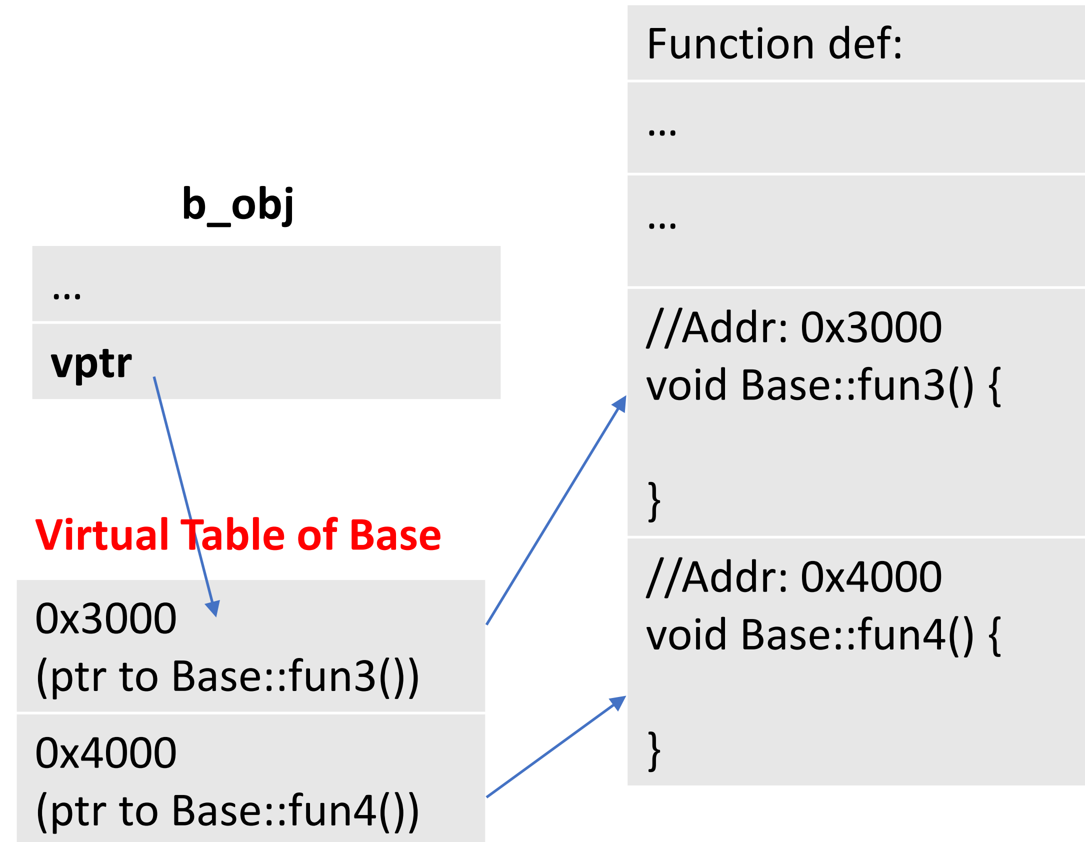
```
class Base {
	private:
		int var;
	public:
		void fun1()
		void fun2()
		virtual voi
		virtual void fun4();
};

Base b_obj;
```

- Memory Layout



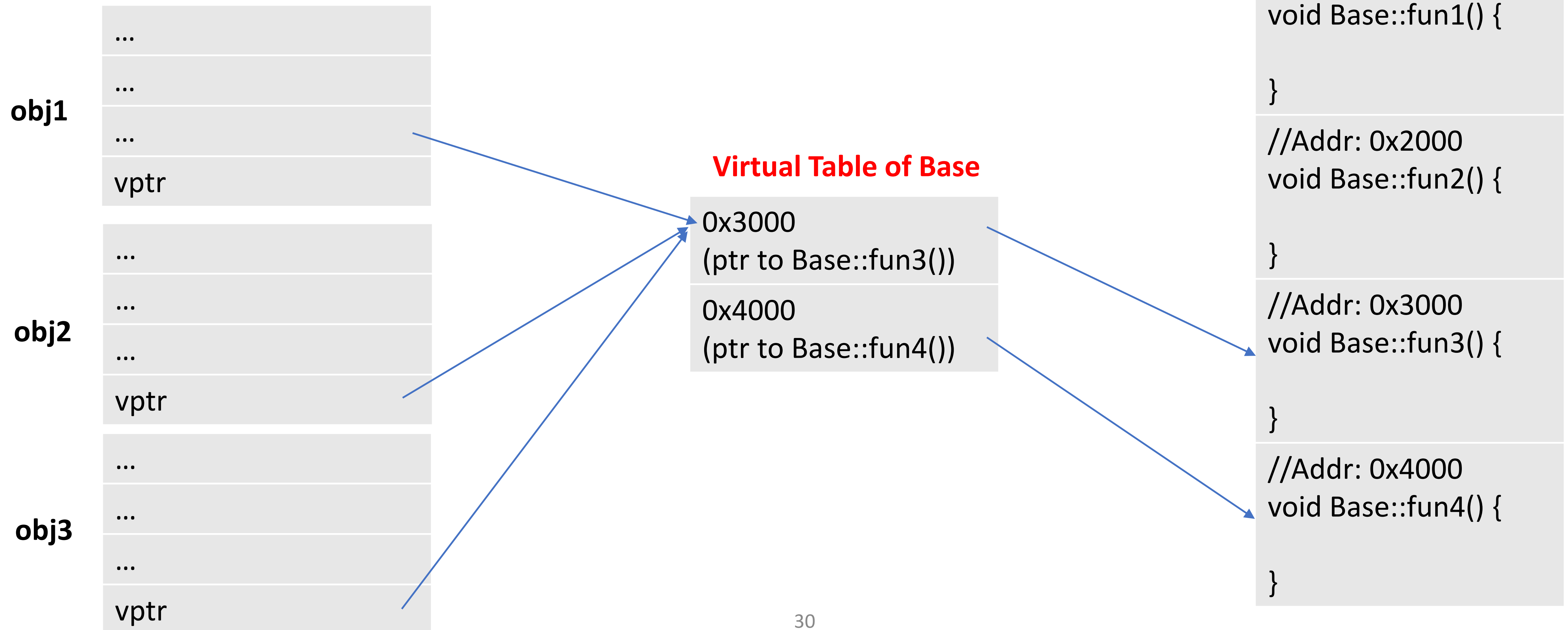
Memory layout of virtual functions

- vptr (**Virtual Pointer**)
  - The pointer which contains address of the Virtual Table
  - vptr is associated with **object**, meaning that each object of that class is having a different vptr pointing to the same Virtual Table
- Virtual Table (**VTable**)
  - A memory space reserved by compiler to place address of virtual functions
  - VTable is associated with **class**, meaning that there will be at most 1 for each class, no matter how many objects of that class have been created. All objects of that class will share the same VTable



Memory layout of virtual functions

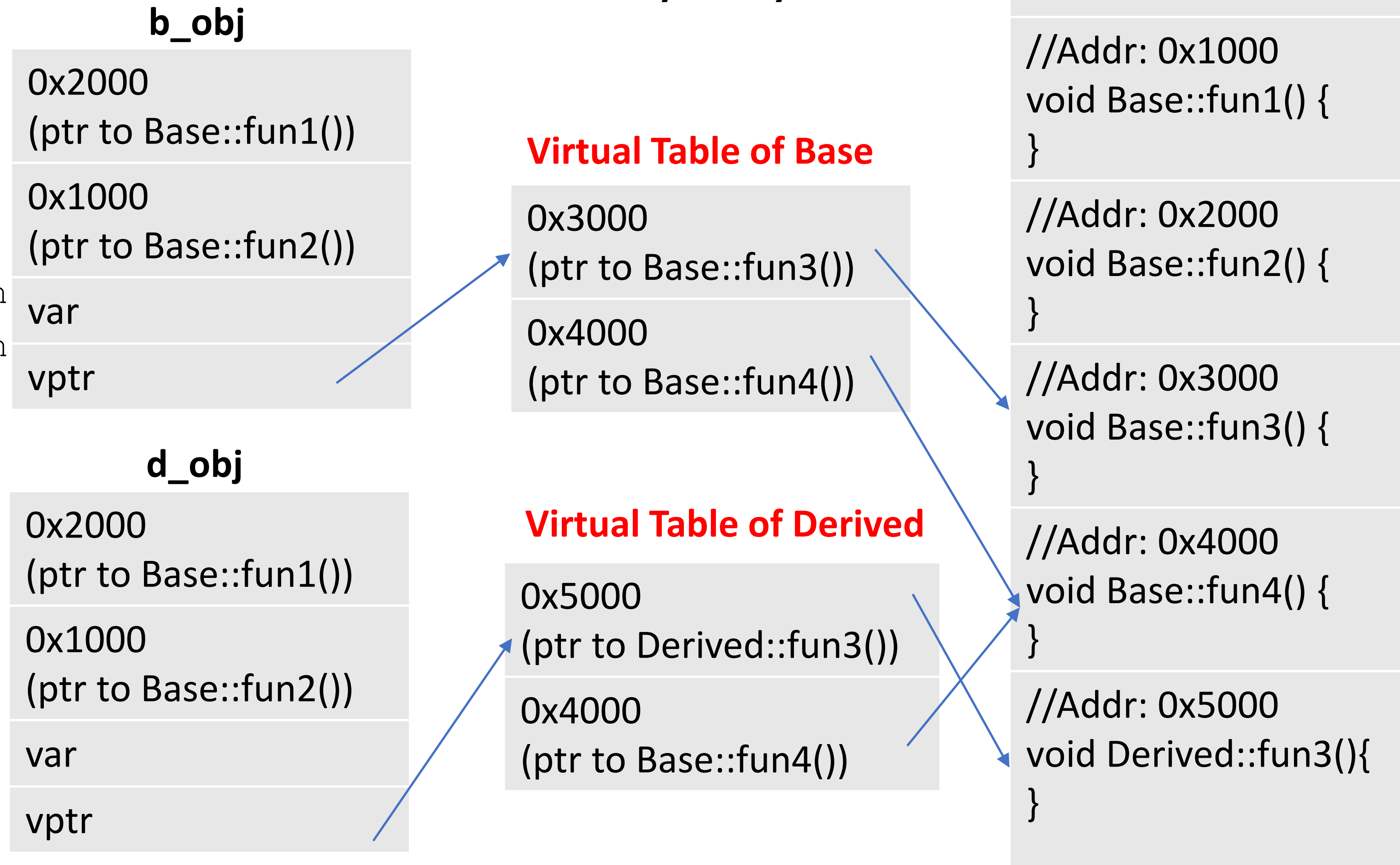
- Memory layout for obj1, obj2, and obj3:



Memory layout of virtual functions

- Let's add a class derived from Base

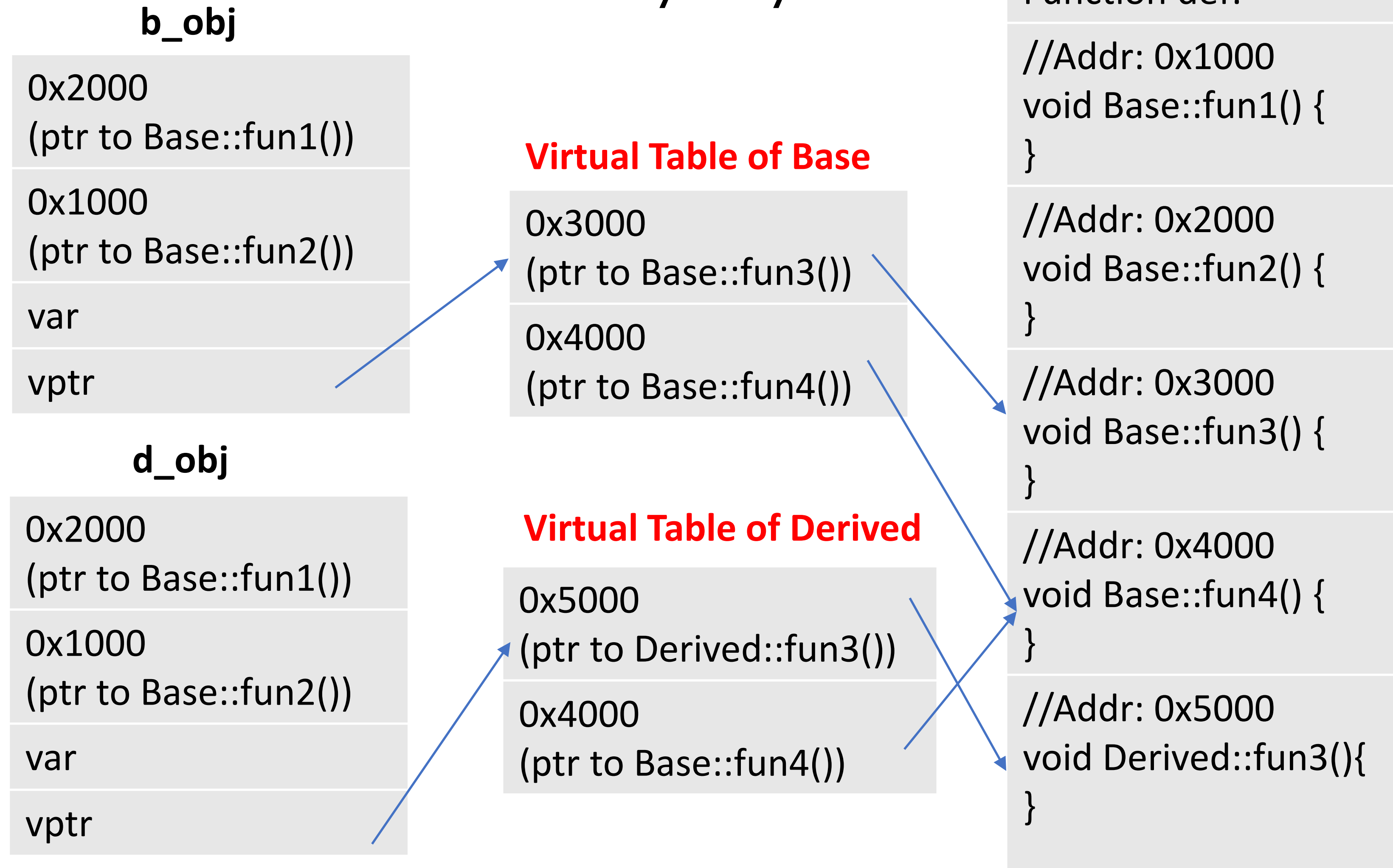
```
class Base {
        private:
                int var;
        public:
                void fun1();
                void fun2();
                virtual void fun
                virtual void fun
};
class Derived : public Base {
        public:
                void fun3();
};
Base b_obj; Derived d_obj;
```



Memory layout of virtual functions

- Let's invoke these methods

```
Base *b_ptr;
Base b_obj;
Derived d_obj;

b_obj.fun3();

b_ptr = &b_obj;
b_ptr->fun3();

b_ptr = &d_obj;
b_ptr->fun3();
```



Virtual Destructors

- Let's define destructors for our `Animal`, `Monkey`, `Sea_Otter`, and `Sloth` class

- Demo…

- We've created a `Monkey` object, but only the `Animal` destructor is being called.
  - If we'd allocated memory in the `Monkey` class that were relying on the destructor to clean, that memory would never be freed, resulting in a memory leak.

Virtual Destructors

- Thus, when using polymorphism, **it's very important to make your base class's destructor virtual**

- Demo…

Additional notes:

- When you declare a function as virtual in a base class, it automatically becomes virtual in all classes derived from that base class, whether you declare it as virtual there or not

- This form of polymorphism works with references as well as pointers.

```
Animal &a = m1;

a.make_noise(); // will call the make_noise() in Monkey class if it is declared to be virtual in the animal class
```

  - This allows us to pass an Monkey object into a function that takes a reference to an Animal object as an argument

    ```
    void some_func(Animal& a);
    ```

    Call: `some_func(m1);`

Abstract classes

- Abstract class
  - can only be used as a base class
  - you cannot instantiate objects of an abstract class

- A class becomes abstract when it has at least one virtual function without a definition
  - Such a function is known as a **pure virtual function**
- To declare a pure virtual function, simply set it equal to zero:

```
class Animal{
      public:
            …
            virtual void make_noise() = 0; //=0 means no definition
};
```

Abstract classes

```
class Animal{
        public:
                …
                virtual void make_noise() = 0; //=0 means no definition
};
```

- Because the `make_noise()` is purely virtual, the `Animal` class becomes an abstract class. That means we cannot create an `Animal` object, i.e. both of these becomes errors:

```
Animal a;
Animal *a = new Animal;
```

- But you can still create pointers of abstract class, and let them point to classes derived from the abstract class, i.e.

```
Animal *a1 = new Monkey;
Animal *a2 = new Sloth;
a1->make_noise() // call make_noise() of Monkey
a2->make_noise() // call make_noise() of Sloth
```

Use of Abstract Classes

- Note: each pure virtual function needs a definition in all its derived class(es)

- All the common code in derived classes is written in abstract class
  - Same as normal inheritance, why we need abstract class?

Use of Abstract Classes

- Let's consider our demo…
- Make `make_noise()` pure virtual in `Animal` class
  - Why? Because every animal can make different noises
  - We wanted all derived class to define this function in their class to make noises
- Demo …

- `Animal` now has become abstract class
- Is there any use of `Animal` class objects?
  - No, they represent nothing.
  - So we need abstract class to prevent making objects of that class
- If you let any 3rd party to implement a `Tiger` class, making `Animal` abstract will enforce them to implement the `make_noise()` in the `Tiger` class