CS 162
Intro to Computer Science II

Lecture 18

Polymorphism

2/28/24

Oregon State University

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(4); // 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.

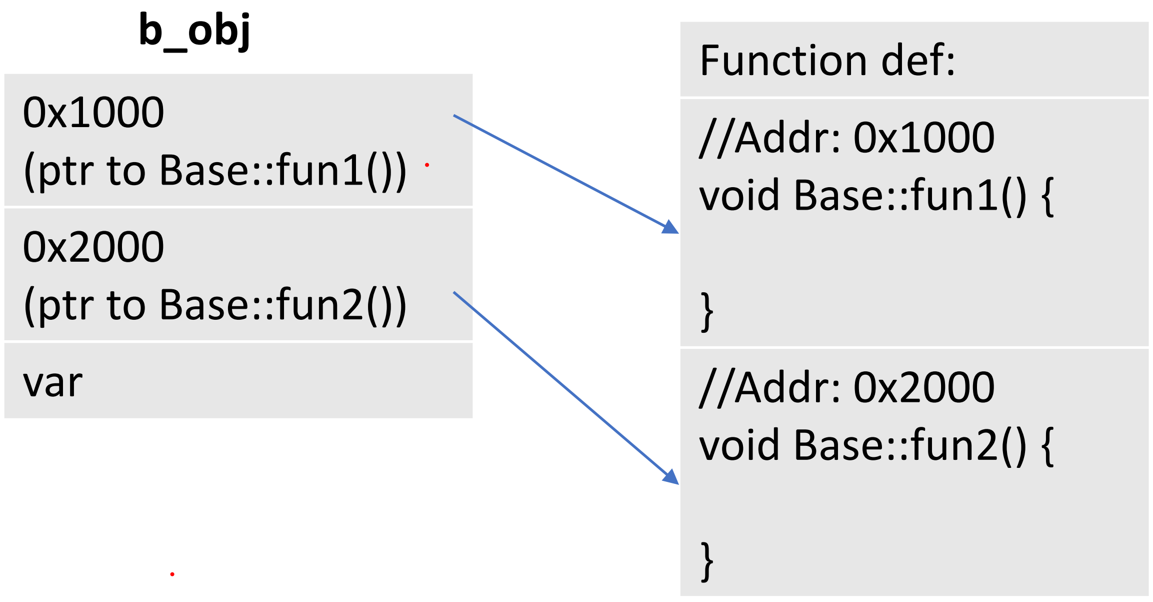
- This is true polymorphism: a pointer to an `Animal` object is being treated differently depending on what kind of object it actually points to.

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

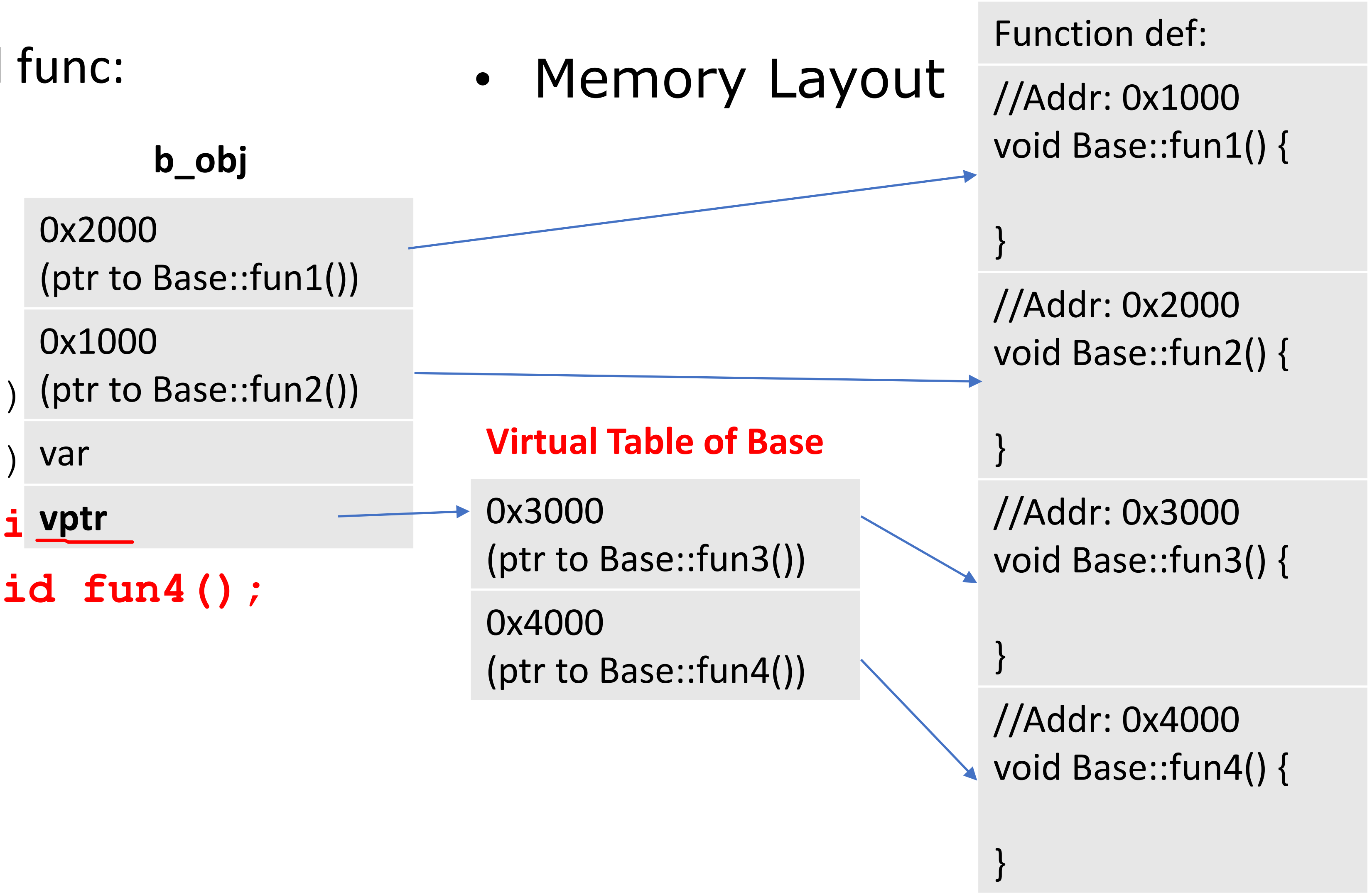


Memory layout of virtual functions

- Now, let’s add two virtual func:

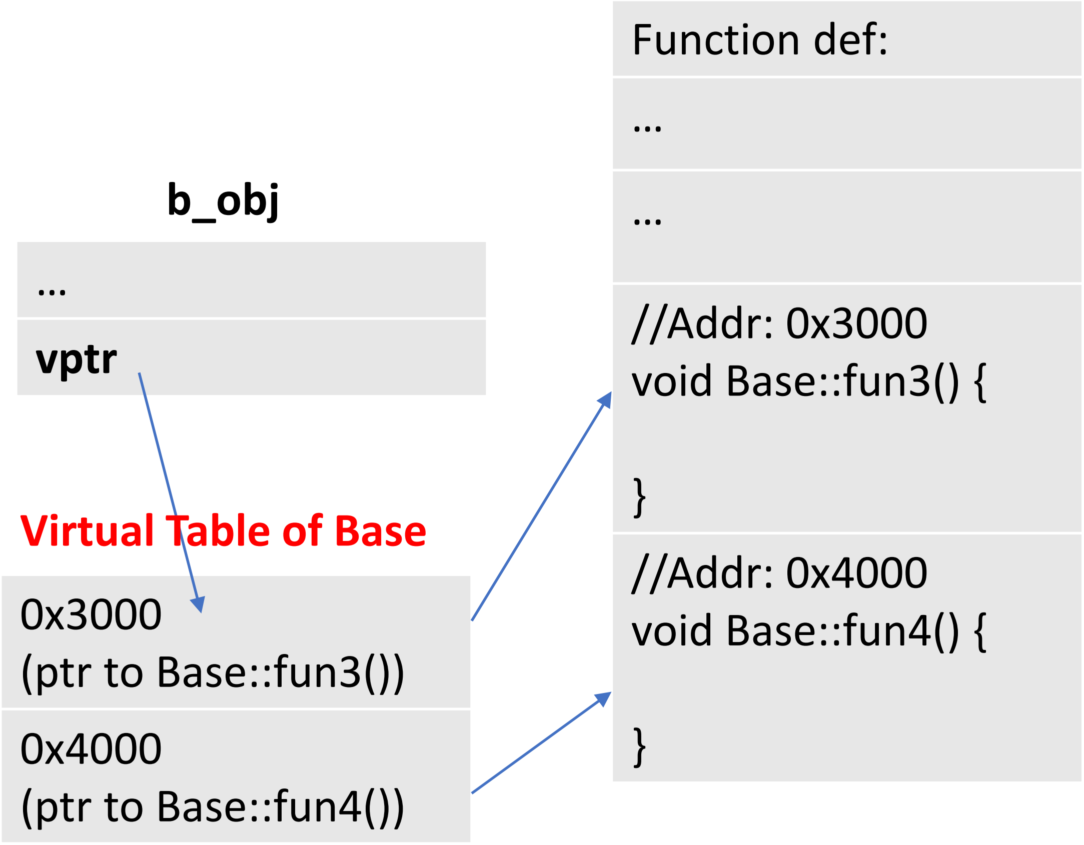
```
class Base {
	private:
		int var;
	public:
		void fun1()
		void fun2()
		virtual voi
		virtual void fun4();
};

Base b_obj;
```

- Memory Layout



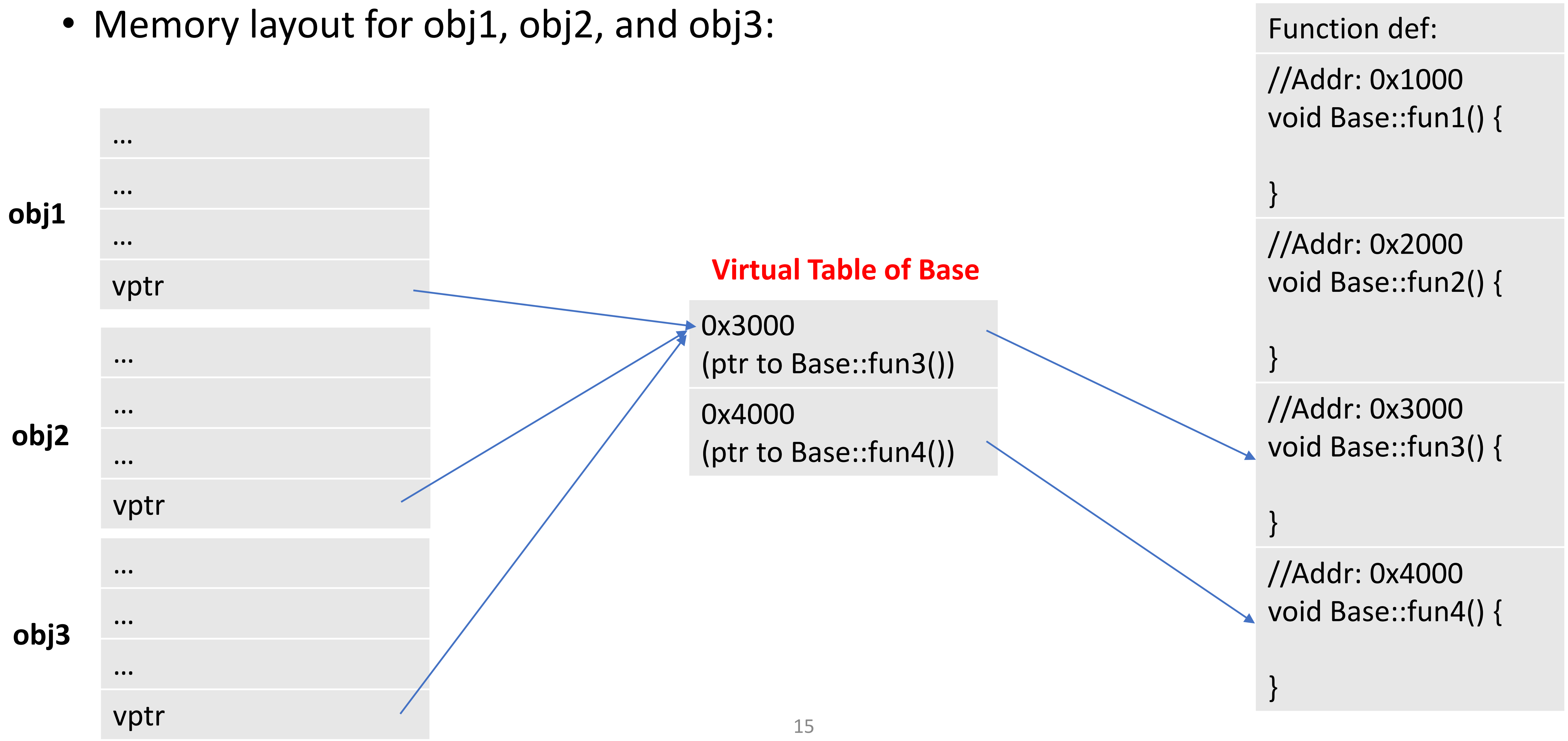
Memory layout of virtual functions

- 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:

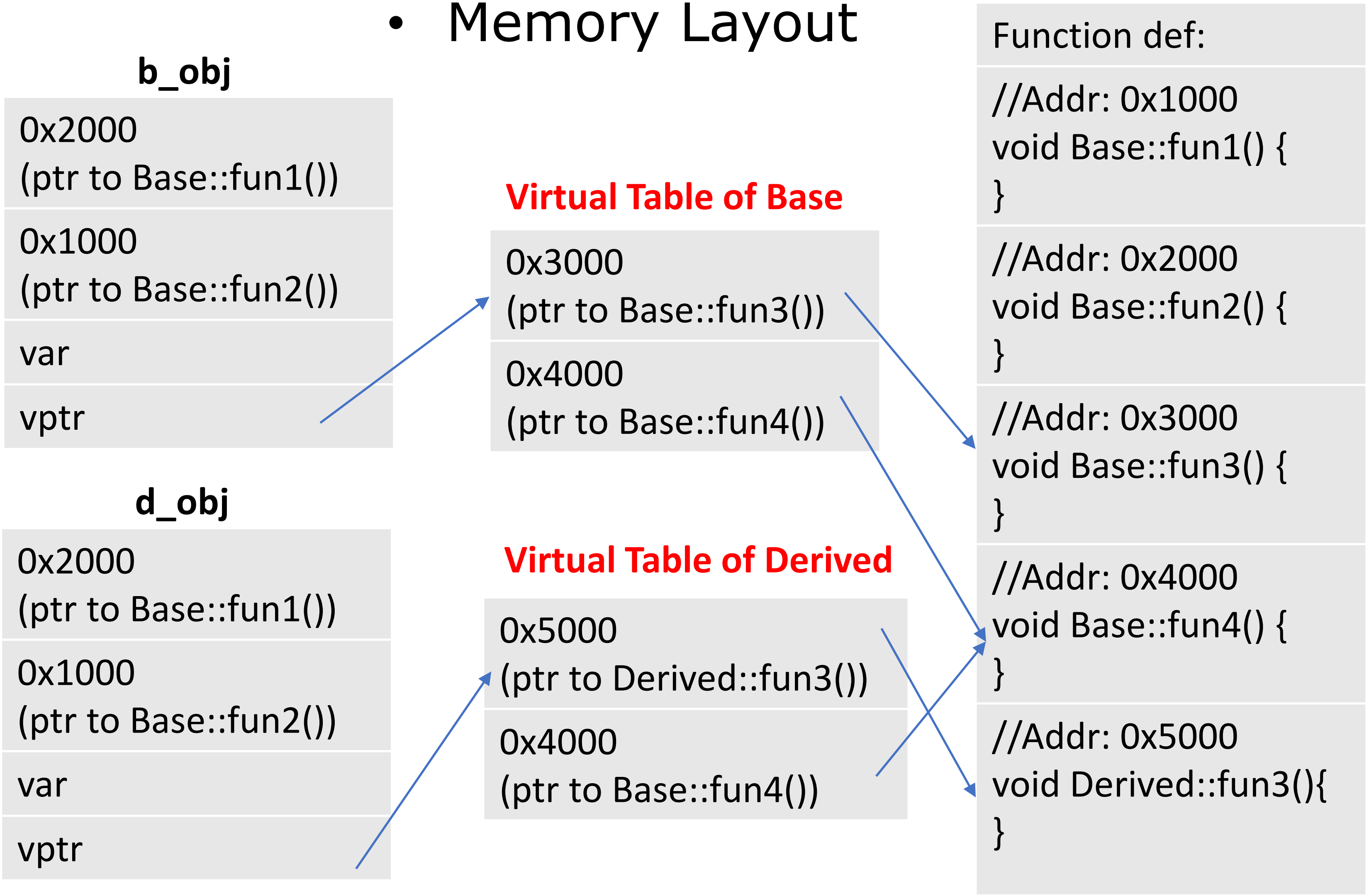


Memory layout of virtual functions

- 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

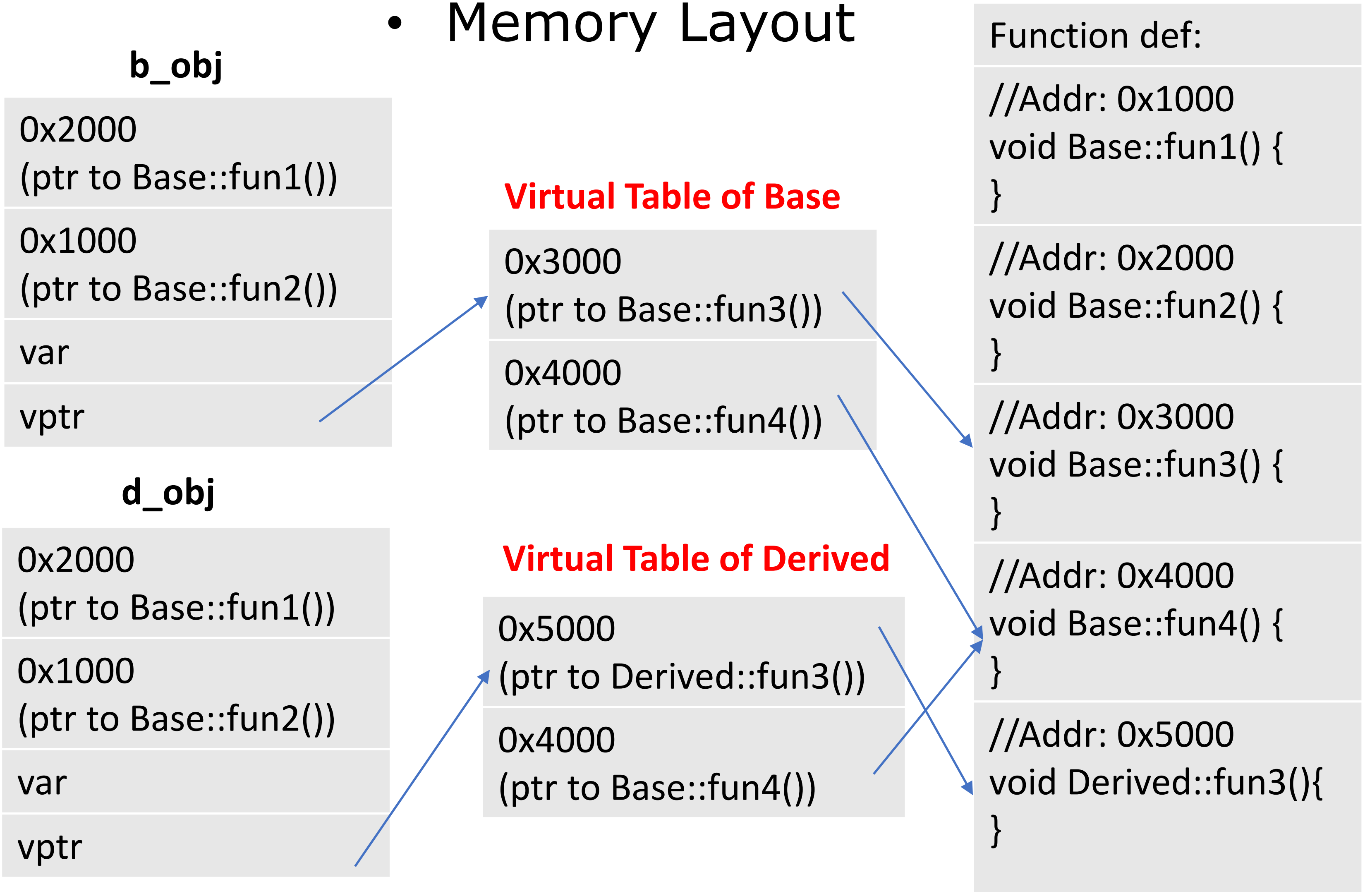


Memory layout of virtual functions

- 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();
```

- Memory Layout



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

Vector: Example of a template class

- Arrays that can grow and shrink in length while the program is running
- Formed from template class in the Standard Template Library (STL)
- Has a base type and stores a collections of this base type: `vector <int> v;`
- Still starts indexing at 0, can still use `[]` to access things
- Use `push_back()` to add one element to the end
- Number of elements == `size`
- How much memory currently allocated == `capacity`

More vectors

- We need to `#include <vector>` to use `std::vector`
- We use `push_back()` to add elements
- Use `pop_back()` to get rid of the last element
- `size()` – how many elements inside the vector
- `capacity()` – how many elements it can hold (allocated memory)
- We can use `operator[]` or `at()` to access specific elements
  - i.e.

    `vec[1]` or `vec.at(1)`
  - Note: `[]` does not throw an exception for an `out-of-range` that `at()` does

More vectors

- To make 2D vectors:

```
vector <vector<int> > vec_2d;
for (int i = 0; i < row; i++){
      vector<int> row_vec;
      for (int j = 0; j < col; j++)
            row_vec.push_back(i * j);
      vec_2d.push_back(row_vec);
}
```

- Note:
  - We need the extra space between angle brackets in the declaration of `vec_2d`, to tell it from the `>>` operator

More vectors

- `std::vector` has a lot more functionalities:
  - It has constructors that allow us to initialize the vector with a specified size and even a specified initial value:

```
vector <int> vec1(20); // Allocate vector of size 20
vector <int> vec2(10,7); // Fill vector with 10 7s
```

More vectors

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  - It has constructors that allow us to initialize the vector with a specified size and even a specified initial value:

```
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```

  - `.size()` – returns the size of the vector
  - `.resize()` – changes size
  - `.empty()` – test whether the vector is empty
  - `.front()` – access the first element
  - `.back()` – access the last element
  - `.clear()` – clear content
  - `.swap()` – swap content

- More: https://cplusplus.com/reference/vector/vector/