CS 162
Intro to Computer Science II

Lecture 19

Virtual vs. Pure virtual, Abstract class

Vector

3/1/24

Oregon State University

Odds and Ends

- Due Sunday 3/3 midnight
  - Quiz 4

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.

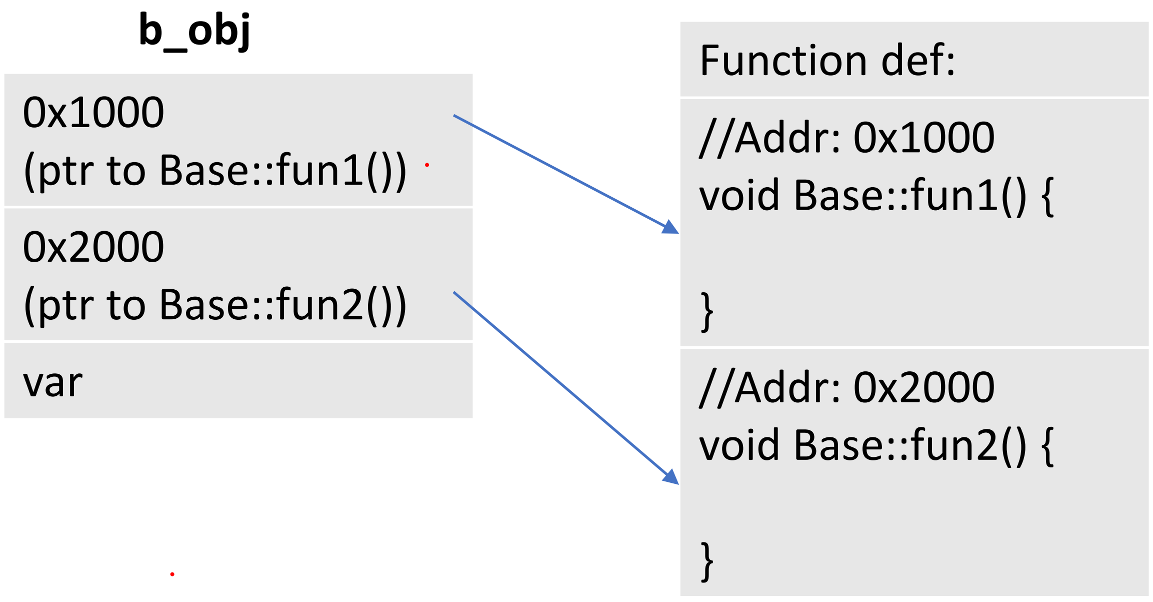
- This is true polymorphism: a pointer to an `Animal` object is being treated differently depending on what kind of object it actually points to.

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

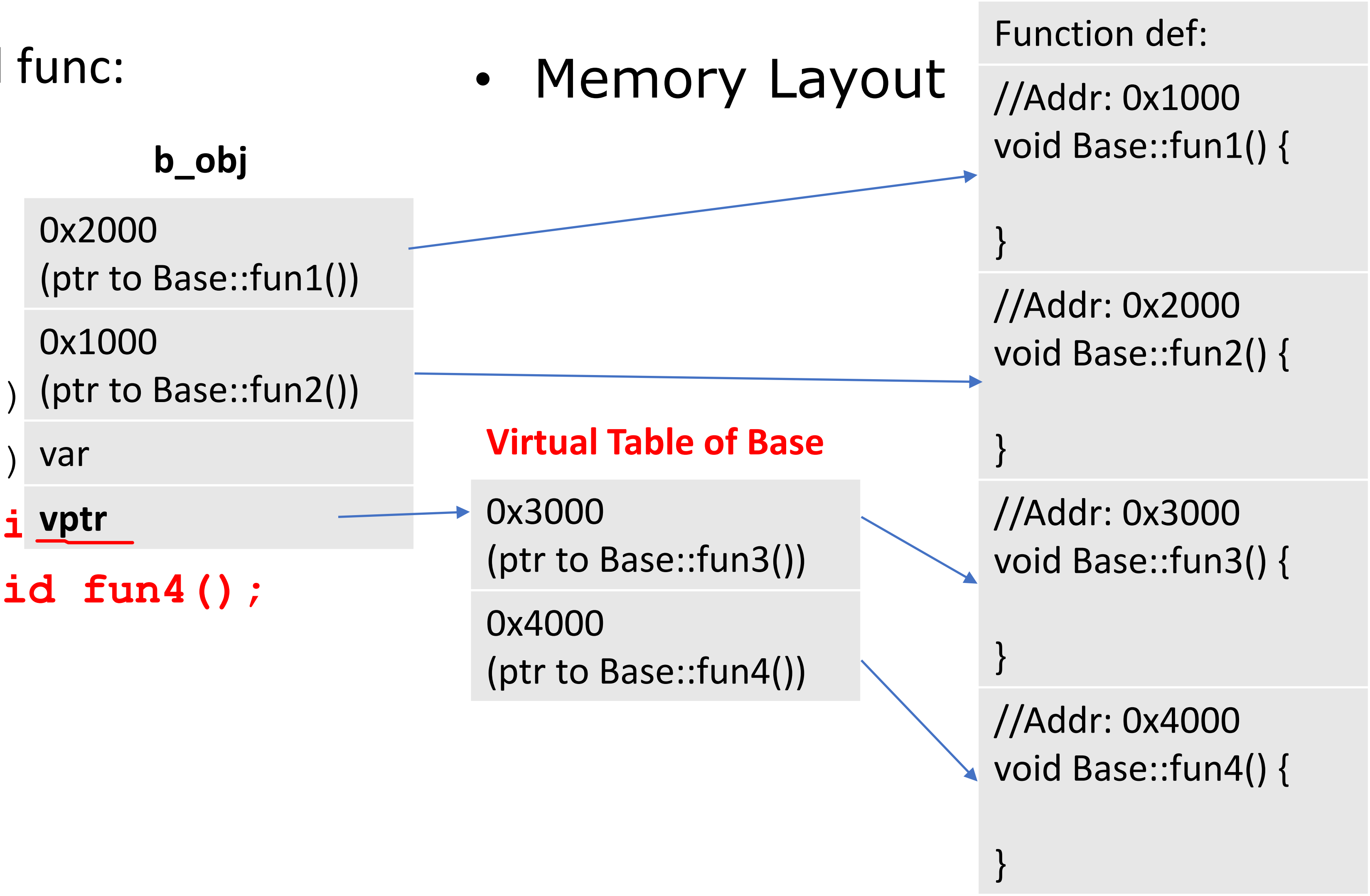


Memory layout of virtual functions

- Now, let's add two virtual func:

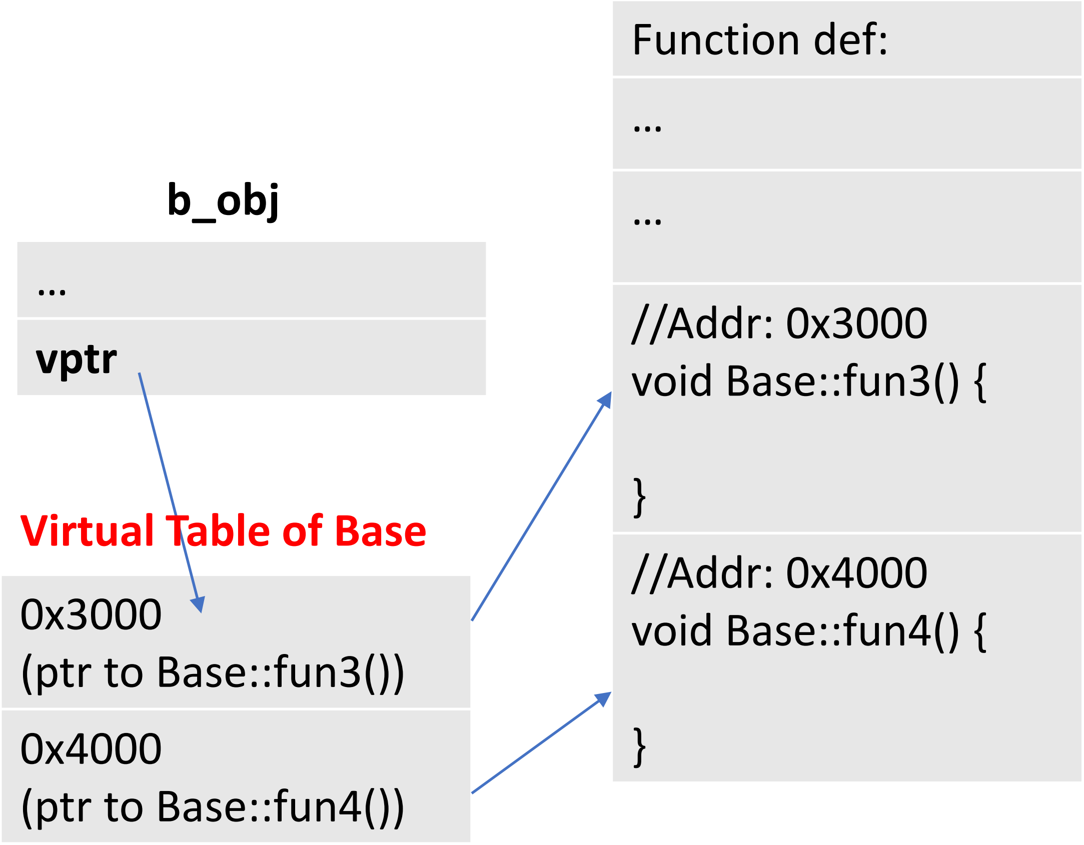
```
class Base {
        private:
                int var;
        public:
                void fun1()
                void fun2()
                virtual voi
                virtual void fun4();
};

Base b_obj;
```

- Memory Layout



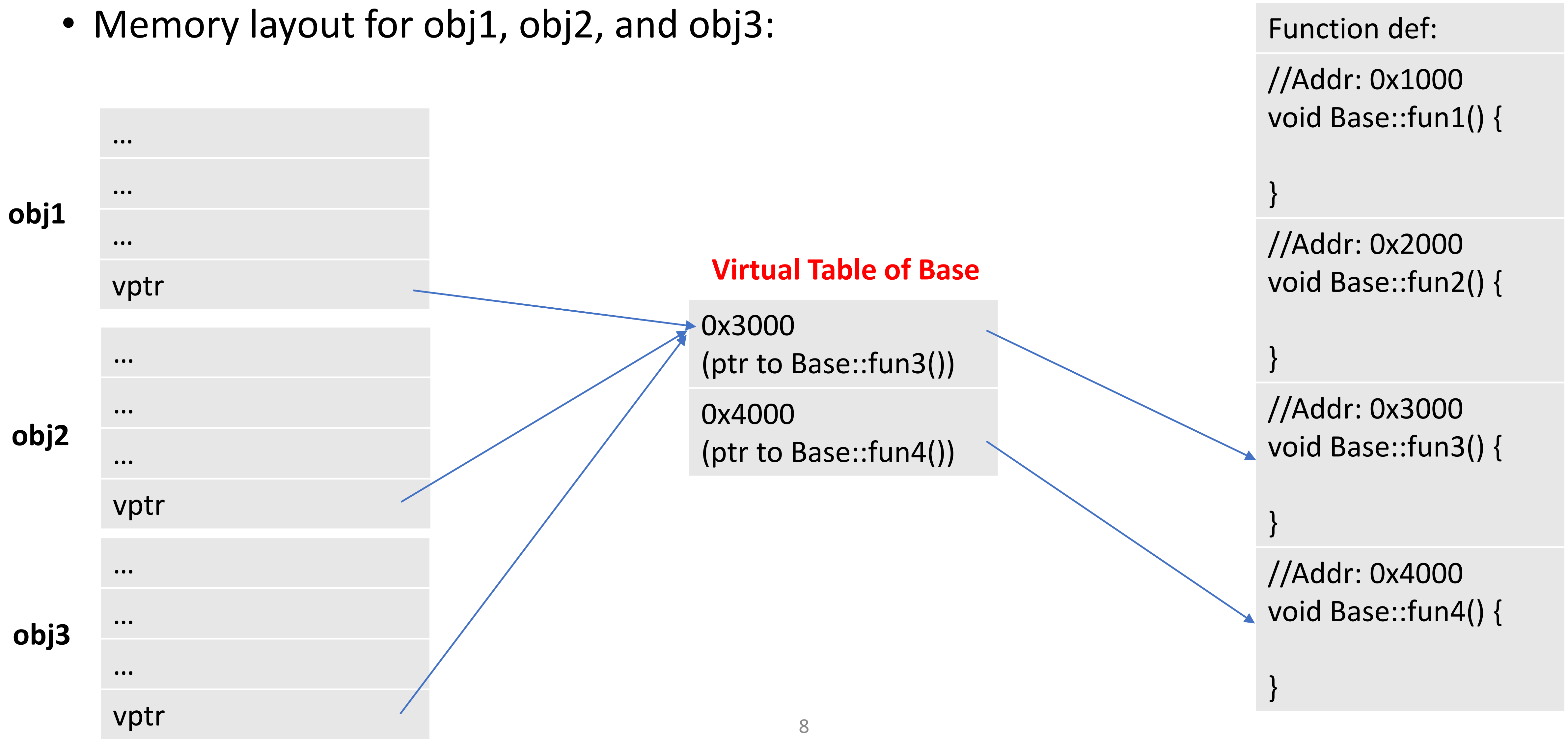
Memory layout of virtual functions

- 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

b_obj

0x2000 (ptr to Base::fun1())
0x1000 (ptr to Base::fun2())
var
vptr

d_obj

0x2000 (ptr to Base::fun1())
0x1000 (ptr to Base::fun2())
var
vptr

Virtual Table of Base

0x3000 (ptr to Base::fun3())
0x4000 (ptr to Base::fun4())

Virtual Table of Derived

0x5000 (ptr to Derived::fun3())
0x4000 (ptr to Base::fun4())

Function def:

//Addr: 0x1000
void Base::fun1() {
}

//Addr: 0x2000
void Base::fun2() {
}

//Addr: 0x3000
void Base::fun3() {
}

//Addr: 0x4000
void Base::fun4() {
}

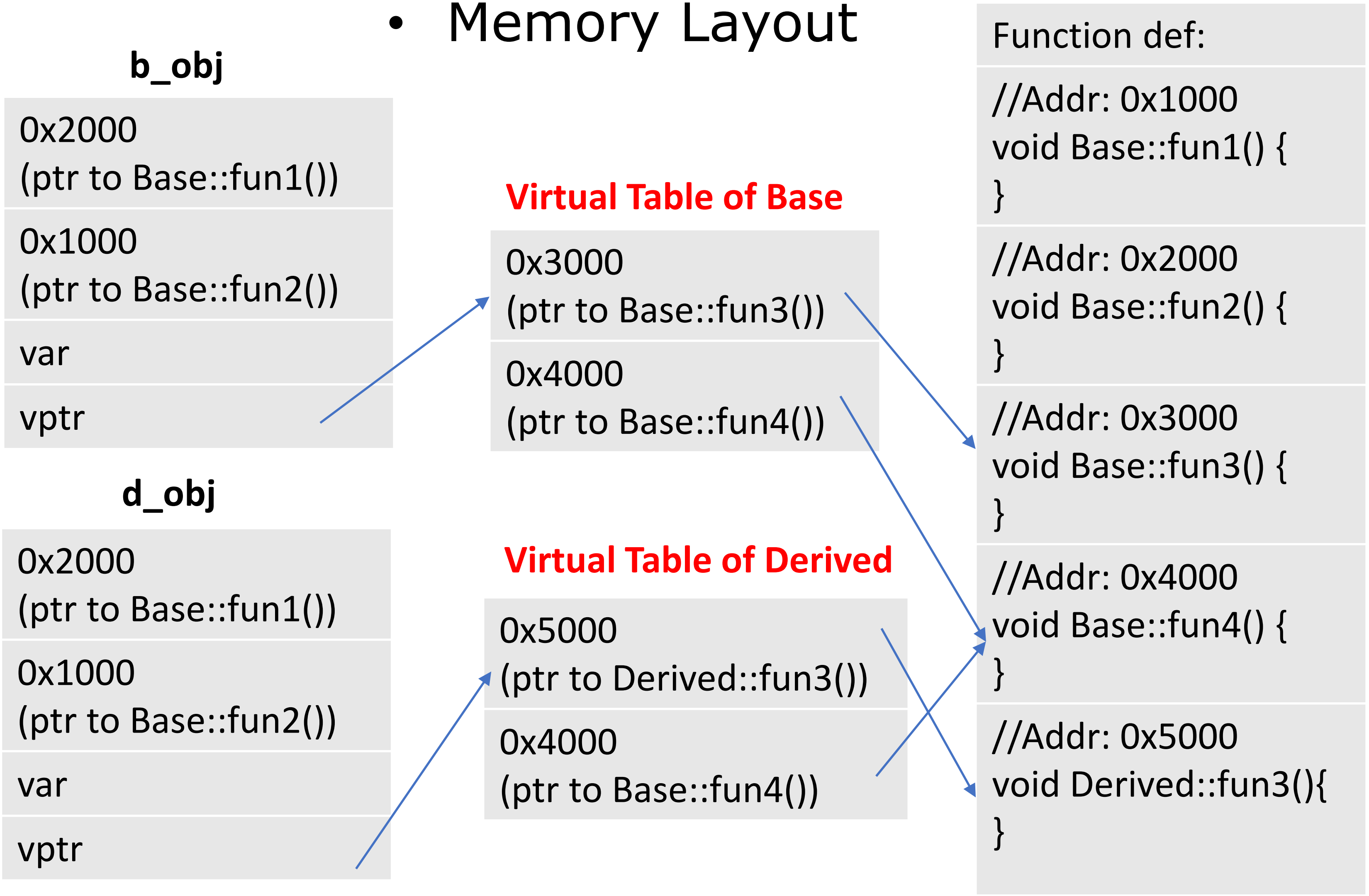
//Addr: 0x5000
void Derived::fun3(){
}

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:

    ```
    vector <int> vec1(20); // Allocate vector of size 20
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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/