Intermediate Programming

Day 33

Outline

- Exercise 32
- Dynamic dispatch
- Function hiding and abstract classes
- Virtual destructors
- Review questions

Exercise 32: Fix compilation errors

Aclass.h

```
...

class A
{
private:
	int a;

protected:
	double d;
	...
```

Bclass.h

```
...

class B : public A
{
private:
	int b;

public:
	B(int val = 0): b(val) { };
	B(int bval, int aval, double dval ) :
		A(aval, dval), b(bval)
	{
		d = 17;
		a = 27;
		...
```

main1.cpp

```
...

int main( void )
{
	A aobj(1);
	A *aptr;
	B bobj(2);
	B *bptr;
	...
	 aobj.d = 17.5;
	...
	aptr->setb(15);
	...
	A a5(5);
	bobj = a5;
	...

}
```

Exercise 32: Fix compilation errors

Aclass.h

```
...

class A
{
private:
	int a;

protected:
	double d;
	...
```

Bclass.h

```
...

class B : public A
{
private:
	int b;

public:
	B(int val = 0): b(val) { };
	B(int bval, int aval, double dval ) :
		A(aval, dval), b(bval)
	{
		d = 17;
		a = 27;
		...
```

main1.cpp

```
...

int main( void )
{
	A aobj(1);
	A *aptr;
	B bobj(2);
	B *bptr;
	...
	 aobj.d = 17.5;
	...
	aptr->setb(15);
	...
	A a5(5);
	bobj = a5;
	...

}
```

Exercise 32: Fix compilation errors

Aclass.h

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class A
{
private:
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	double d;
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Bclass.h

```
...

class B : public A
{
private:
	int b;

public:
	B(int val = 0): b(val) { };
	B(int bval, int aval, double dval ) :
		A(aval, dval), b(bval)
	{
		d = 17;
		// a = 27;
		...
```

main1.cpp

```
...

int main( void )
{
	A aobj(1);
	A *aptr;
	B bobj(2);
	B *bptr;
	...
	aobj.d = 17.5;
	...
	aptr->setb(15);
	...
	A a5(5);
	bobj = a5;
	...

}
```

Exercise 32: Fix compilation errors

Aclass.h

```
...

class A
{
private:
	int a;

protected:
	double d;
	...
```

Bclass.h

```
...

class B : public A
{
private:
	int b;

public:
	B(int val = 0): b(val) { };
	B(int bval, int aval, double dval ) :
		A(aval, dval), b(bval)
	{
		d = 17;
		// a = 27;
		...
```

main1.cpp

```
...

int main( void )
{
	A aobj(1);
	A *aptr;
	B bobj(2);
	B *bptr;
	...
	 // aobj.d = 17.5;
	...
	aptr->setb(15);
	...
	A a5(5);
	bobj = a5;
	...

}
```

Exercise 32: Fix compilation errors

Aclass.h

```
...

class A
{
private:
	int a;

protected:
	double d;
	...
```

Bclass.h

```
...

class B : public A
{
private:
	int b;

public:
	B(int val = 0): b(val) { };
	B(int bval, int aval, double dval ) :
		A(aval, dval), b(bval)
	{
		d = 17;
		a = 27;
		...
```

main1.cpp

```
...

int main( void )
{
	A aobj(1);
	A *aptr;
	B bobj(2);
	B *bptr;
	...
	 aobj.d = 17.5;
	...
	// aptr->setb(15);
	...
	A a5(5);
	bobj = a5;
	...

}
```

Exercise 32: Make *A::show* virtual

Aclass.h

```
...

class A
{
	...
public:
	void show() { std::cout << "A is " << a << std::endl; test(); }
	...
```

Bclass.h

```
...

class B
{
	...
public:
	void show() { A::show(); std::cout << "B is " << b << std::endl; test(); }
};
	...
```

main1.cpp

```
...
main( void )
{
	A aobj(1);
	A *aptr;
	B bobj(2);
	B *bptr;
	...
	bptr = &bobj;
	aptr = bptr;
	aptr->seta(3);
	aptr->show();
	...
```

```
>> ./main
...
A is 3
test A
...
```

Exercise 32: Make *A::show* virtual

Aclass.h

```
...

class A
{
	...
public:
	virtual void show() { std::cout << "A is " << a << std::endl; test(); }
	...
```

Bclass.h

```
...

class B
{
	...
public:
	void show() { A::show(); std::cout << "B is " << b << std::endl; test(); }
};
	...
```

main1.cpp

```
...
main( void )
{
	A aobj(1);
	A *aptr;
	B bobj(2);
	B *bptr;
	...
	bptr = &bobj;
	aptr = bptr;
	aptr->seta(3);
	aptr->show();
	...
```

```
>> ./main
...
A is 3
test A
B is 2
test B
...
```

Outline

- Exercise 32
- Dynamic dispatch
- Function hiding and abstract classes
- Virtual destructors
- Review questions

Inheritance (casting)

- We can convert from a derived class back to its base
  - The compiler casts to the derived class

account.h

```
#include <string>
class Account
{
public:
	…
	double balance( void ) const { return _balance; }
private:
	double _balance;
};
class CheckingAccount : public Account
{
public:
	…
};
```

main.cpp

```
#include <iostream>
#include "account.h"
using namespace std;
void PrintBalance( const Account acct )
{
	cout << "Balance: " << acct.balance() << endl;
}
int main( void )
{
	Account acct( 1000 );
	CheckingAccount cAcct( 5000 );
	PrintBalance( acct );
	PrintBalance( cAcct );
	return 0;
}
```

```
>> ./a.out
Balance: 1000
Balance: 5000
>>
```

Inheritance (slicing)

- We can convert from a derived class back to its base
  - The compiler "slices out" the derived class

account.h

```
#include <string>
class Account
{
public:
	…
	double balance( void ) const { return _balance; }
private:
	double _balance;
};
class CheckingAccount : public Account
{
public:
	…
};
```

main.cpp

```
#include <iostream>
#include "account.h"
using namespace std;
void PrintBalance( const Account &acct )
{
	cout << "Balance: " << acct.balance() << endl;
}
int main( void )
{
	Account acct( 1000 );
	CheckingAccount cAcct( 5000 );
	PrintBalance( acct );
	PrintBalance( cAcct );
	return 0;
}
```

```
>> ./a.out
Balance: 1000
Balance: 5000
>>
```

Inheritance (slicing)

- We can convert from a derived class back to its base
  - The compiler "slices out" the derived class

account.h

```
#include <string>
class Account
{
public:
	…
	double balance( void ) const { return _balance; }
private:
	double _balance;
};
class CheckingAccount : public Account
{
public:
	…
};
```

main.cpp

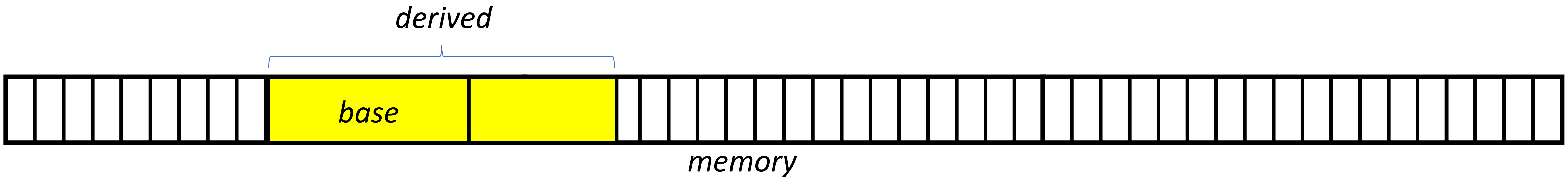
```
#include <iostream>
#include "account.h"
using namespace std;
void PrintBalance( const Account *acct )
{
	cout << "Balance: " << acct->balance() << endl;
}
int main( void )
{
	Account acct( 1000 );
	CheckingAccount cAcct( 5000 );
	PrintBalance( &acct );
	PrintBalance( &cAcct );
	return 0;
}
```

```
>> ./a.out
Balance: 1000
Balance: 5000
>>
```

Inheritance

Under the hood:

When the compiler lays out a derived object in memory, it puts the data of the base class first

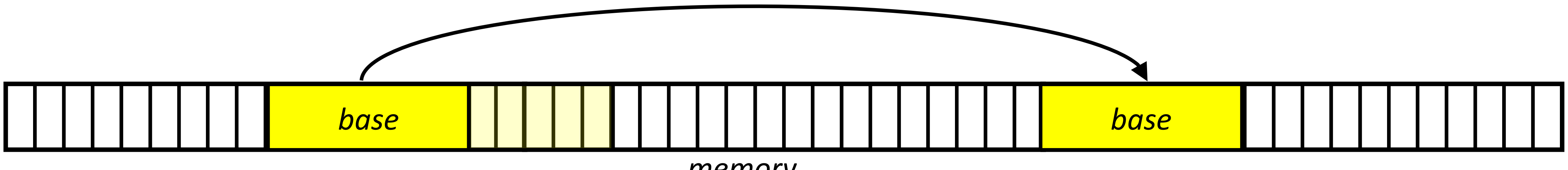


Inheritance (casting)

Under the hood:

When the compiler lays out a derived object in memory, it puts the data of the base class first

- To cast to the derived class, the compiler copies the contents of the base and ignores the contents of memory past the base data



Inheritance (slicing)

Under the hood:

When the compiler lays out a derived object in memory, it puts the data of the base class first

- To cast to the derived class, the compiler copies the contents of the base and ignores the contents of memory past the base data
- To slice out the derived class, the compiler ignores the contents of memory past the base data

⇒ The address of the derived object is the same as the address of the base

⇒ A reference to the derived object is a reference to the base

Inheritance (dynamic dispatch)

- We can tell the compiler to determine the "true" type of a class **as it invokes certain methods**, and use the implementation of that class

account.h

```cpp
#include <string>
class Account
{
public:
	…
	virtual std::string type( void ) const { return "generic"; }
};
class CheckingAccount : public Account
{
public:
	…
	std::string type( void ) const { return "checking"; }
};
```

main.cpp

```cpp
#include <iostream>
#include "account.h"
void PrintType( const Account& a )
{
	std::cout << "Type: " << a.type() << std::endl;
}
int main( void )
{
	Account acct( 1000 );
	CheckingAccount cAcct( 5000 );
	PrintType( acct );
	PrintType( cAcct );
	return 0;
}
```

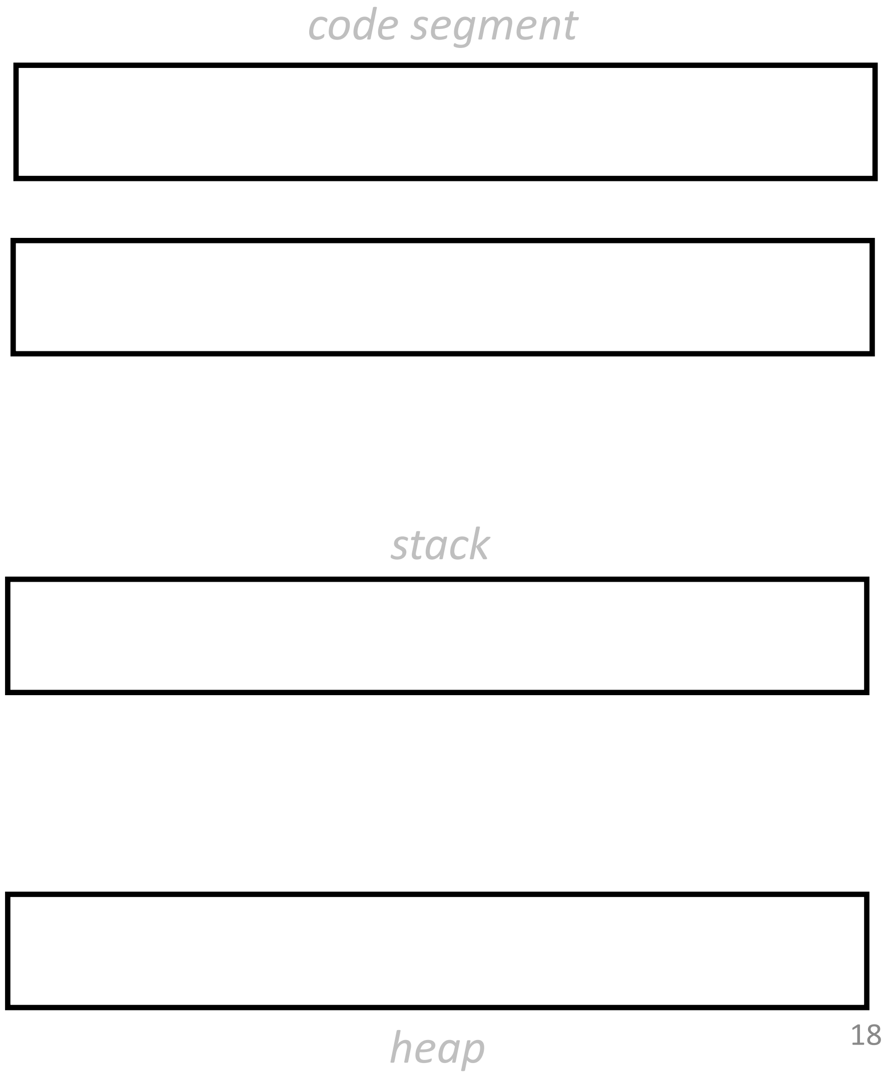
```
>> ./a.out
Type: generic
Type: checking
>>
```

Inheritance (dynamic dispatch)

<u>Under the hood</u>:

When we previously talked about the memory layout, we talked about the *stack* and the *heap*.

This was a little simplified. There is also the *code segment*. This is where the code resides in memory.



c dispatch)

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k and the *heap*.

e is also the
code segment. This is where the code resides

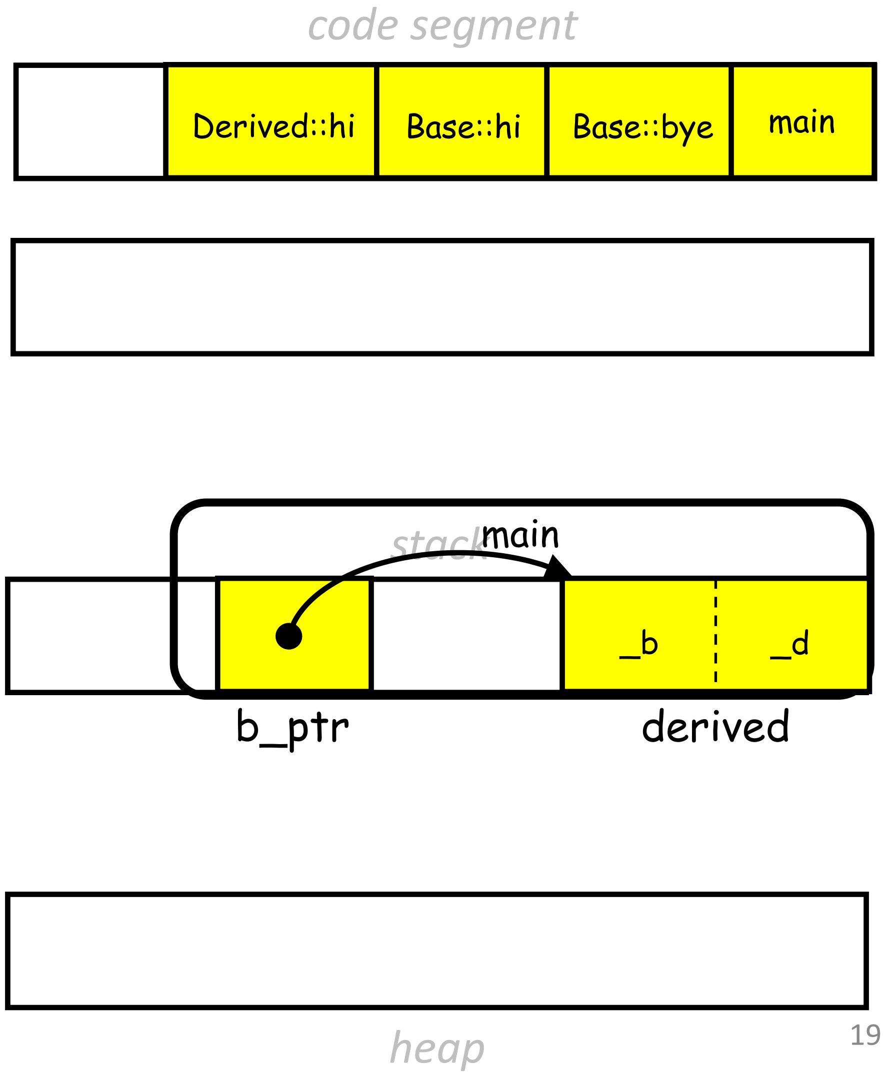
main.cpp (part 1)

```
#include <iostream>

class Base
{
        double _b;
public:
        void hi(){ std::cout << "hi(base)" << std::endl; }
        void bye() { std::cout << "bye(base)" << std::endl; }
};

class Derived : public Base
{
        double _d;
public:
        void hi(){ std::cout << "hi(derived)" << std::endl; }
};
```

main.cpp (part 2)

```
int main( void )
{
        Derived derived;
        Base *b_ptr = &derived;
        b_ptr->hi();
        b_ptr->bye();
        return 1;
}
```

```
>> ./a.out
hi(base)
bye(base)
>>
```

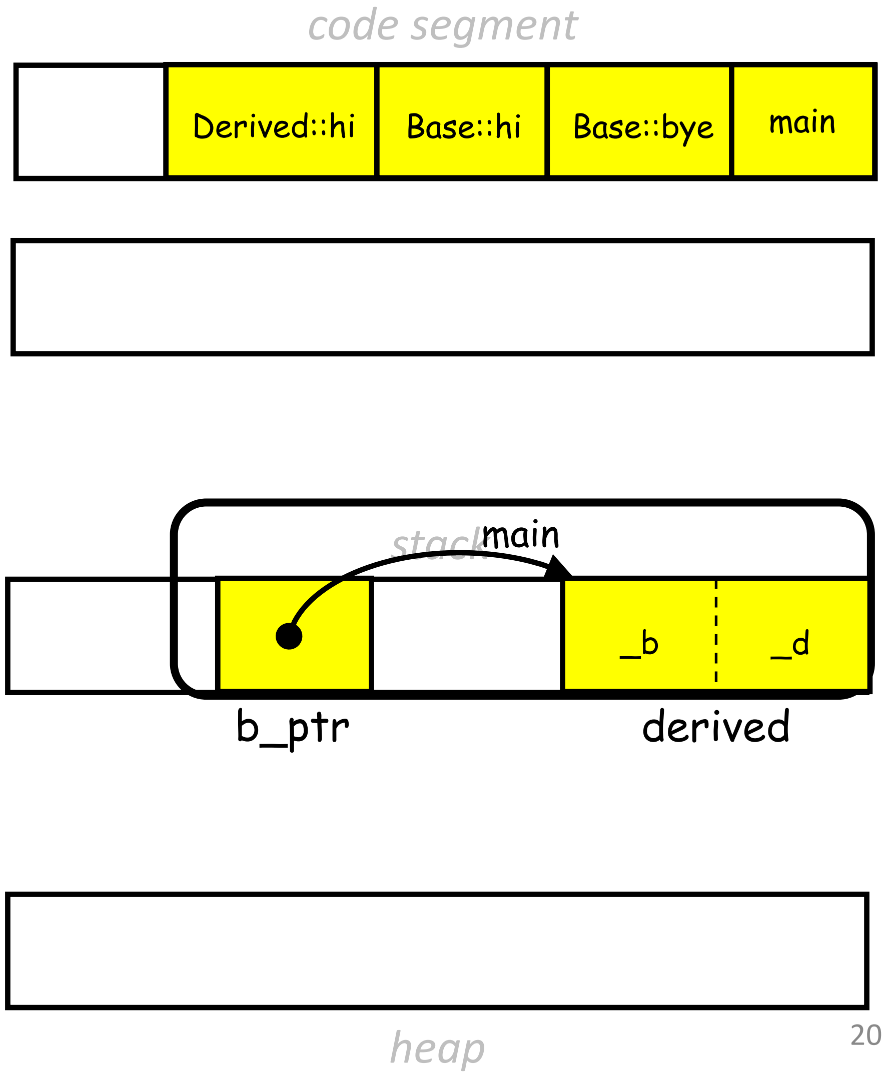


Inheritance (dynamic dispatch)

Under the hood:

When a class has virtual member functions:

1. The compiler creates a *virtual function table* for the class listing the addresses of its **most derived** virtual functions
2. The compiler adds a (hidden) member to the base class, pointing to the class's virtual function table
3. When an object is created, the pointer points to the class's virtual function table



main.cpp (part 1)

```
#include <iostream>

class Base
{
	double _b;
public:
	virtual void hi(){ std::cout << "hi(base)" << std::endl; }
	virtual void bye() { std::cout << "bye(base)" << std::endl; }
};

class Derived : public Base
{
	double _d;
public:
	void hi(){ std::cout << "hi(derived)" << std::endl; }
};
```

main.cpp (part 2)

```
int main( void )
{
	Derived derived;
	Base *b_ptr = &derived;
	b_ptr->hi();
	b_ptr->bye();
	return 1;
}
```

```
>> ./a.out
hi(derived)
bye(base)
>>
```

c dispatch)

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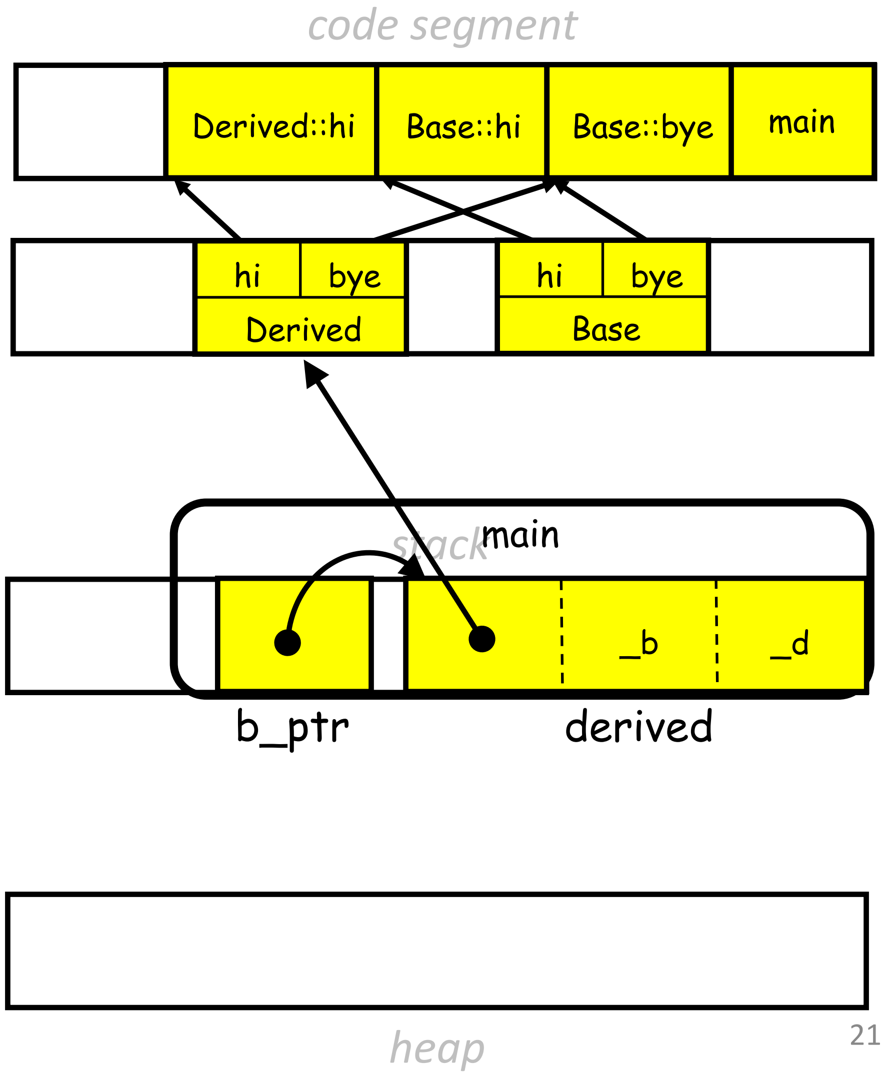
member to the

ss's virtual

he pointer points

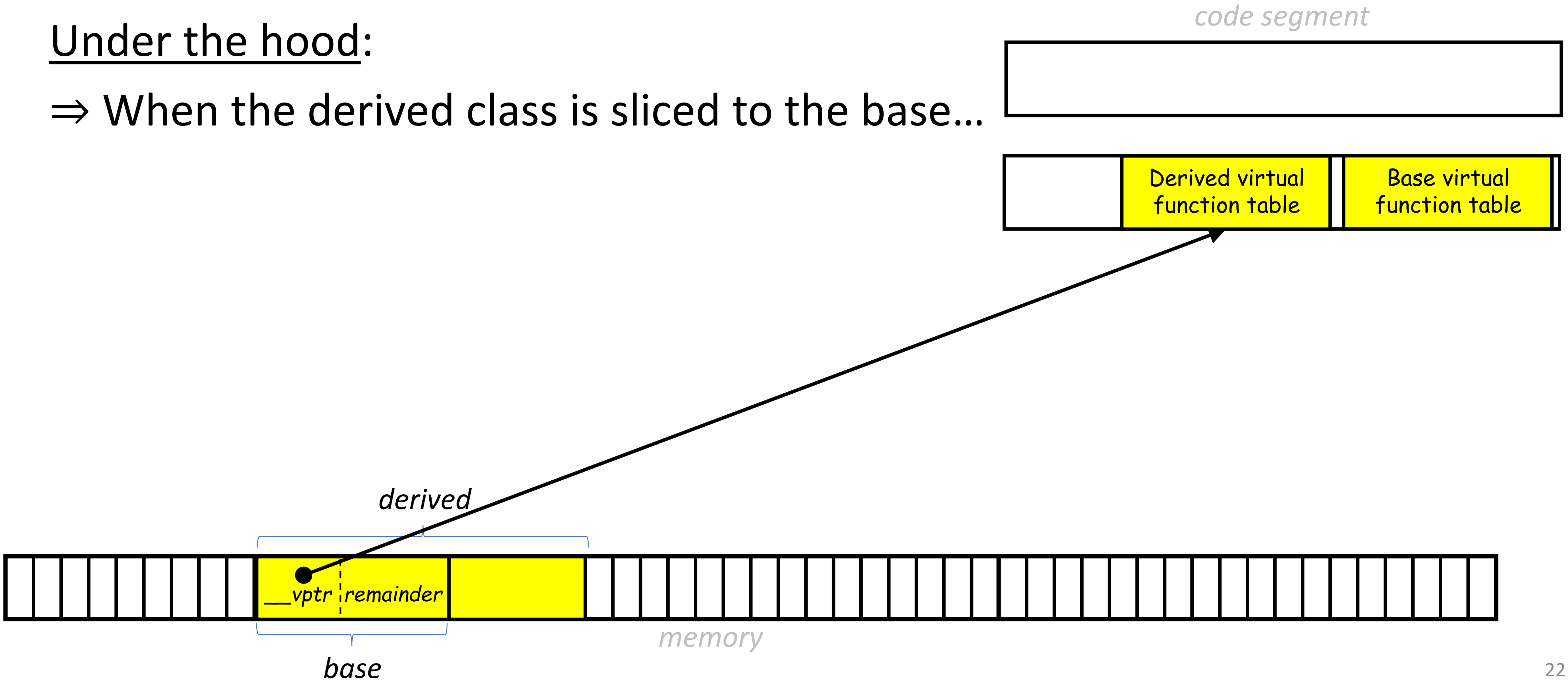
table



Inheritance (dynamic dispatch)

Under the hood:

⇒ When the derived class is sliced to the base…

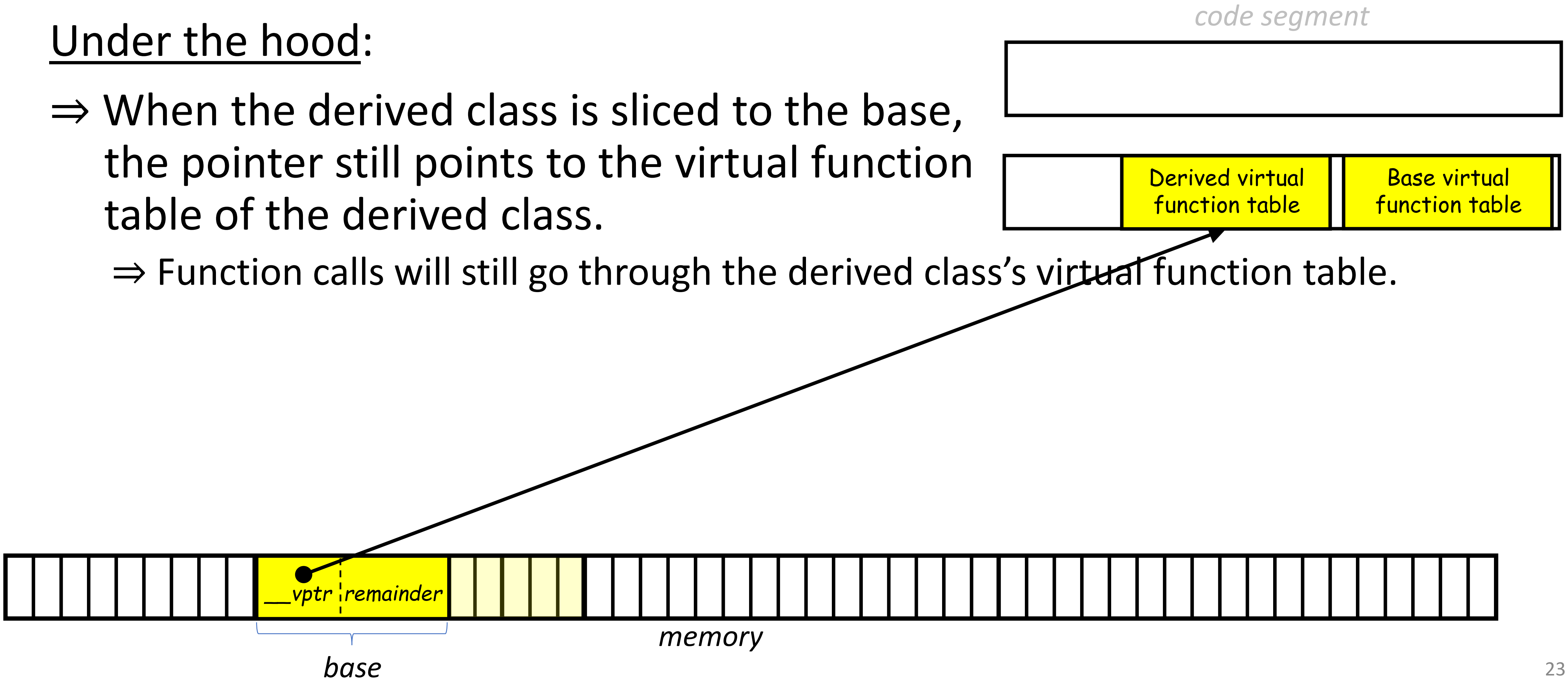


Inheritance (dynamic dispatch)

<u>Under the hood</u>:

⇒ When the derived class is sliced to the base, the pointer still points to the virtual function table of the derived class.

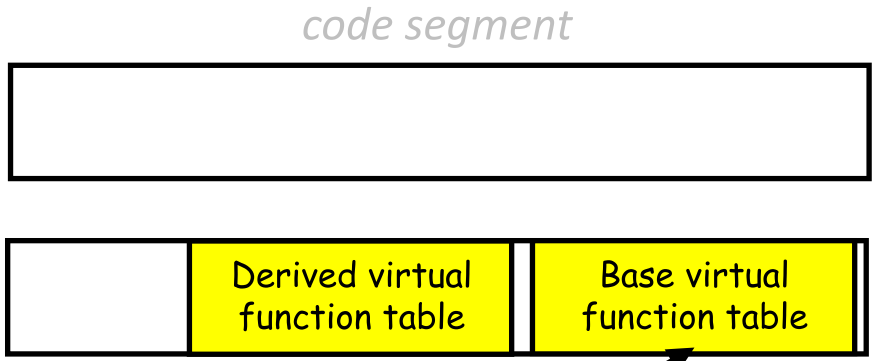
⇒ Function calls will still go through the derived class's virtual function table.



Inheritance (dynamic dispatch)

<u>Under the hood</u>:

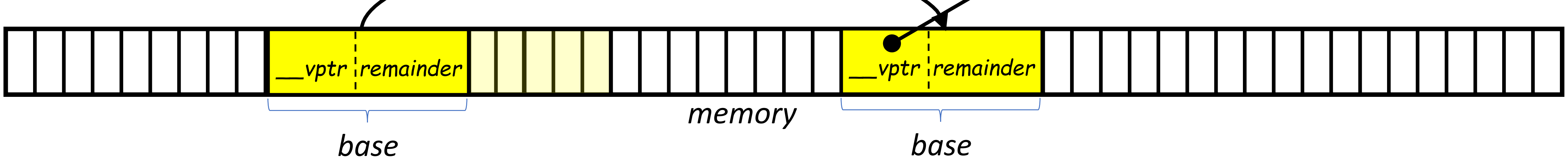
⇒ When the derived class is sliced to the base, the pointer still points to the virtual function table of the derived class.



⇒ Function calls will still go through the derived class's virtual function table.

⇒ When the derived class is cast to the base, the unhidden member data is copied **but** the pointer is set to the virtual function table of the base class.

⇒ Function calls will go through the base class's virtual function table



Inheritance (dynamic dispa

Warning:

To override, a base class's function the signatures (function's name, arguments, and `const` designators) have to match.

baseDerived.h

```
#include <string>

class Base
{
public:
	virtual std::string type( void ) const { return "base"; }
};

class Derived : public Base
{
public:
	std::string type( void ) { return "derived"; }
};
```

main.cpp

```
#include <iostream>
#include "baseDerived.h"

int main( void )
{
	Derived derived;
	Base &base = derived;
	std::cout << base.type() << std::endl;
	return 0;
}
```

```
>> ./a.out
base
>>
```

Inheritance (dynamic dispa

baseDerived.h

```
#include <string>

class Base
{
public:
	virtual std::string type( void ) const { return "base"; }
};

class Derived : public Base
{
public:
	std::string type( void ) override { return "derived"; }
};
```

main.cpp

```
#include <iostream>
#include "baseDerived.h"

int main( void )
{
	Derived derived;
	Base &base = derived;
	std::cout << base.type() << std::endl;
	return 0;
```

<u>Warning</u>:

To override, a base class's function the signatures (function's name, arguments, and `const` designators) have to match.

You can protect your code by specifying that the derived method should **override** the base method.

```
>> g++ main.cpp ...
In file included from foo.cpp:2:
baseDerived.h:12:15: error: 'std::string Derived::type()' marked 'override', but does not override
   12 |   std::string type( void ) override { return "derived"; }
      |               ^~~~
>>
```

Outline

- Exercise 32
- Dynamic dispatch
- Function hiding and abstract classes
- Virtual destructors
- Review questions

Function hiding

- When a derived class defines a member function with the same **name** (not necessarily signature), the base class's member function becomes hidden, even if it's the better match.

main.cpp

```
#include <iostream>

using namespace std;

class Base
{
public:
	void foo( int ){ cout << "base" << endl; }
};

class Derived : public Base
{
public:
	void foo( double ){ cout << "derived" << endl; }
};

int main( void )
{
	Derived d;
	d.foo( 1 );
	d.foo( 1. );
	return 0;
}
```

```
>> ./a.out
derived
derived
>>
```

Function hiding

- When a derived class defines a member function with the same **name** (not necessarily signature), the base class's member function becomes hidden, even if it's the better match.
- In fact, the base class's member function becomes hidden, even if the derived class cannot match the argument list.

main.cpp

```
#include <iostream>

using namespace std;

class Base
{
public:
	void foo( int , int ){ cout << "base" << endl; }
};

class Derived : public Base
{
public:
	void foo( double ){ cout << "derived" << endl; }
};

int main( void )
{
	Derived d;
	d.foo( 1 , 1 );
	return 0;
}
```

Function hiding

- When a derived class defines a member function with the same **name** (not necessarily signature), the base class's member function becomes hidden, even if it's the better match.
- In fact, the base cla
function becomes
if the derived class
the argument list.

main.cpp

```
#include <iostream>

using namespace std;

class Base
{
public:
	void foo( int , int ){ cout << "base" << endl; }
};

class Derived : public Base
{
public:
	void foo( double ){ cout << "derived" << endl; }
};
```

```
>> g++ main.cpp ...
main.cpp: In function ‘int main()’:
main.cpp:20:15: error: no matching function for call to ‘Derived::foo(int, int)’
   20 |  d.foo( 1 , 1 );
      |               ^
main.cpp:14:8: note: candidate: ‘void Derived::foo(double)’
   14 |   void foo( double ){ cout << "derived" << endl; }
      |        ^~~
main.cpp:14:8: note:   candidate expects 1 argument, 2 provided
>>
```

Inheritance (pure **virtual** functions)

- You can declare a function to be **pure virtual** by setting it "=0"
- This makes the class **abstract** because it has undefined function members
  - ⇒ You cannot create an object of the base type because it will be abstract.

main.cpp

```
#include <iostream>
class Base
{
public:
	virtual void print( void ) const = 0;
};
class Derived : public Base
{
public:
	void print( void ) const
	{ std::cout << "derived" << std::endl; }
};
int main( void )
{
	Base b;
	return 0;
}
```

Inheritance (pure **virtual** functions)

- You can declare a function to be **pure virtual** by setting it "=0"
- This makes the class **abstract** because it has undefined function members
  - ⇒ You cannot create an object of the base type because it will be abstract

main.cpp

```
#include <iostream>
class Base
{
public:
        virtual void print( void ) const = 0;
};
class Derived : public Base
{
...
d::endl; }
```

```
>> g++ main.cpp ...
main.cpp: In function 'int main()':
main.cpp:14:6: error: cannot declare variable 'b' to be of abstract type 'Base'
   14 | Base b;
      |      ^
main.cpp:2:7: note:   because the following virtual functions are pure within 'Base':
    2 | class Base
      |       ^~~~
main.cpp:5:14: note:     'virtual void Base::print() const'
    5 | virtual void print( void ) const = 0;
      |              ^~~~~
>>
```

Inheritance (pure **virtual** functions)

- You can declare a function to be **pure virtual** by setting it "=0"
- This makes the class **abstract** because it has undefined function members
  - ⇒ You cannot create an object of the base type because it will be abstract.
  - ⇒ You can create a derived object if the derived class defines the method

main.cpp

```
#include <iostream>
class Base
{
public:
	virtual void print( void ) const = 0;
};
class Derived : public Base
{
public:
	void print( void ) const
	{ std::cout << "derived" << std::endl; }
};
int main( void )
{
	Derived d;
	return 0;
}
```

Inheritance (pure **virtual** functions)

- You can declare a function to be **pure virtual** by setting it "=0"
- This makes the class **abstract** because it has undefined function members
  - ⇒ You cannot create an object of the base type because it will be abstract.
  - ⇒ You can create a derived object if the derived class defines the method
  - ⇒ You can have pointers and references to the base object

main.cpp

```
#include <iostream>
class Base
{
public:
	virtual void print( void ) const = 0;
};
class Derived : public Base
{
public:
	void print( void ) const
	{ std::cout << "derived" << std::endl; }
};
int main( void )
{
	Derived d;
	Base &b = d;
	return 0;
}
```

Inheritance (pure **virtual** functions)

- You can declare a function to be **pure virtual** by setting it "=0"
- This makes the class **abstract** because it has undefined function members
- You can also make the class abstract by making its constructor protected.

main.cpp

```
#include <iostream>
class Base
{
protected:
	Base( void ){ std::cout << "base" << std::endl; }
};
class Derived : public Base
{
public:
	Derived( void ) : Base()
	{
		std::cout << "derived" << std::endl;
	}
};
int main( void )
{
	Base b;
	return 0;
}
```

Inheritance (pure **virtual** functions)

- You can declare a function to be **pure virtual** by setting it "=0"
- This makes the class **abstract** because it has undefined function members
- You can also make the class abstract by making its constructor **protected**.

main.cpp

```
#include <iostream>
class Base
{
protected:
    Base( void ){ std::cout << "base" << std::endl; }
};
class Derived : public Base
{
public:
    Derived( void ) : Base()
    {
        std::cout << "derived" << std::endl;
    }

t main( void )

    Base b;
    return 0;
```

```
>> g++ main.cpp ...
main.cpp: In function 'int main()':
main.cpp:17:6: error: 'Base::Base()' is protected within this context
   17 | Base b;
      |      ^
main.cpp:5:2: note: declared protected here
    5 |  Base( void ){ std::cout << "base" << std::endl; }
      |  ^~~~
>>
```

Inheritance (pure **virtual** functions)

- You can declare a function to be **pure virtual** by setting it "=0"
- This makes the class **abstract** because it has undefined function members
- You can also make the class abstract by making its constructor protected.

main.cpp

```
#include <iostream>
class Base
{
protected:
	Base( void ){ std::cout << "base" << std::endl; }
};
class Derived : public Base
{
public:
	Derived( void ) : Base()
	{
		std::cout << "derived" << std::endl;
	}
};
int main( void )
{
	Derived d;
	return 0;
}
```

```
>> ./a.out
base
derived
>>
```

Outline

- Exercise 32
- Dynamic dispatch
- Function hiding and abstract classes
- Virtual destructors
- Review questions

Virtual destructors

- When you slice a derived class to a base class, it is the base class's destructor that is invoked when the object is deleted.

main.cpp

```
#include <iostream>
using namespace std;
class Base
{
public:
	Base( void ){ cout << "base" << endl; }
	~Base( void ) { cout << "~base" << endl; }
};
class Derived : public Base
{
public:
	Derived( void ){ cout << "derived" << endl; }
	~Derived( void ){ cout << "~derived" << endl; }
};
int main( void )
{
	Base *b = new Derived();
	delete b;
	return 0;
}
```

```
>> ./a.out
base
derived
~base
>>
```

Virtual destructors

- When you slice a derived class to a base class, it is the base class's destructor that is invoked when the object is deleted.
- You can declare destructor of the base to be `virtual` to force the derived destructor to be used (e.g. if the derived classes needs to release resources when it is destroyed.)

main.cpp

```
#include <iostream>
using namespace std;
class Base
{
public:
	Base( void ){ cout << "base" << endl; }
	virtual ~Base( void ) { cout << "~base" << endl; }
};
class Derived : public Base
{
public:
	Derived( void ){ cout << "derived" << endl; }
	~Derived( void ){ cout << "~derived" << endl; }
};
int main( void )
{
	Base *b = new Derived();
	delete b;
	return 0;
}
```

```
>> ./a.out
base
derived
~derived
~base
>>
```

Virtual destructors

Rule of thumb:
If a class has virtual member functions, it should also have a virtual destructor.

Virtual member functions

⇓

The derived class could have unforeseen functionality

⇓

The derive class could acquire resources that need to be released

Outline

- Exercise 32
- Dynamic dispatch
- Function hiding and abstract classes
- Virtual destructors
- Review questions

Review questions

1. Explain what object slicing is in C++.

When a pointer/reference to a base class is used to point to/reference a derived object, the compiler “squints” and only looks at the base’s subset of the information.

Review questions

2. What is the keyword `override` in C++?

A way to indicate that a function in a derived class is supposed to override one in a base class

Review questions

3. Explain what function hiding is in C++?

When a function in a derived class has the same name but different parameters than one in its base class

Review questions

4. In C++, how do you make an abstract class?

Include a pure virtual function, or provide a non-public constructor

Review questions

5. Can we create an object from an abstract class?

No

Exercise 33

- Website -> Course Materials -> ex33