601.220 Intermediate Programming

Dynamic dispatch

Dynamic dispatch

- What is **object slicing**?
- How does `virtual` work? (Dynamic dispatch)
- The keyword/modifier `override`

The Account example w/o `virtual`

```
#include <iostream>
#include <string>

using std::cout;  using std::endl;

class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial) : balance(initial) { }

    void credit(double amt)    { balance += amt; }
    void debit(double amt)     { balance -= amt; }
    double get_balance() const { return balance; }
    std::string type() const { return "Account"; }
private:
    double balance;
};

class CheckingAccount : public Account {
public:
    CheckingAccount(double initial, double atm) :
        Account(initial), total_fees(0.0),
            atm_fee(atm) { }
    void cash_withdrawal(double amt) {
        total_fees += atm_fee;
        debit(amt + atm_fee);
    }
    double get_total_fees() const {
        return total_fees;
    }

    std::string type() const {
        return "CheckingAccount";
    }

private:
    double total_fees;
    double atm_fee;
};


void print_account_type(const Account& acct) {
    cout << acct.type() << endl;
}

int main() {
    Account acct(1000.0);
    CheckingAccount checking(1000.0, 2.00);
    print_account_type(acct);
    print_account_type(checking);
    return 0;
}
```

The Account example w/o `virtual`

```
$ g++ -c account1.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o account1 account1.o
$ ./account1
Account
Account
```

It doesn't work without `virtual`

The Account example using `virtual`

```
#include <iostream>
#include <string>

using std::cout;  using std::endl;

class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial) : balance(initial) { }

    void credit(double amt)    { balance += amt; }
    void debit(double amt)     { balance -= amt; }
    double get_balance() const { return balance; }
    virtual std::string type() const { return "Account"; }
private:
    double balance;
};

class CheckingAccount : public Account {
public:
    CheckingAccount(double initial, double atm) :
        Account(initial), total_fees(0.0),
            atm_fee(atm) { }
    void cash_withdrawal(double amt) {
        total_fees += atm_fee;
        debit(amt + atm_fee);
    }
    double get_total_fees() const {
        return total_fees;
    }

    std::string type() const {
        return "CheckingAccount";
    }

private:
    double total_fees;
    double atm_fee;
};

void print_account_type(const Account& acct) {
    cout << acct.type() << endl;
}

int main() {
    Account acct(1000.0);
    CheckingAccount checking(1000.0, 2.00);
    print_account_type(acct);
    print_account_type(checking);
    return 0;
}
```

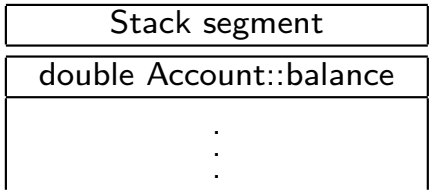
The Account example using `virtual`

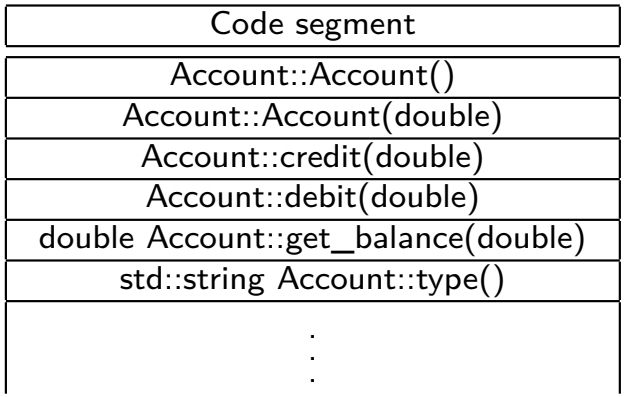
```
$ g++ -c account1.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o account1 account1.o
$ ./account1
Account
CheckingAccount
```

But how does it work internally in C++?

A brief memory layout of a simple class

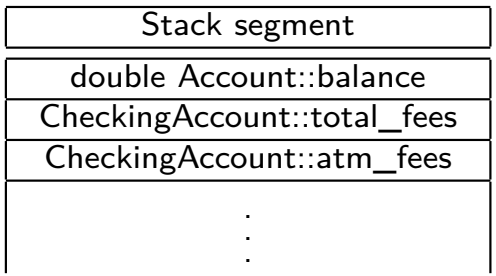
```
class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial)
      : balance(initial) { }

    void credit(double amt) {
        balance += amt;
    }
    void debit(double amt) {
        balance -= amt;
    }
    double get_balance() const {
        return balance;
    }
    std::string type() const {
        return "Account";
    }
private:
    double balance;
};
```

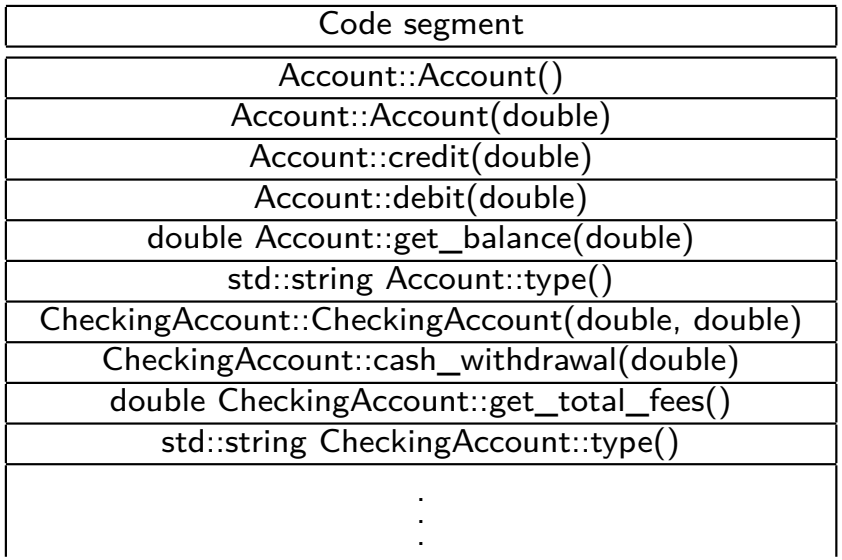




A brief memory layout of a simple derived class

```
class CheckingAccount : public Account {
public:
    CheckingAccount(double initial, double atm) :
    Account(initial), total_fees(0.0),
    atm_fee(atm) { }
    void cash_withdrawal(double amt) {
        total_fees += atm_fee;
        debit(amt + atm_fee);
    }
    double get_total_fees() const
    {
        return total_fees;
    }

    std::string type() const {
        return "CheckingAccount";
    }

private:
    double total_fees;
    double atm_fee;
};
```





Brief memory layouts of base and derived class

Base class:

Stack segment
double Account::balance
. . .

Derived class:

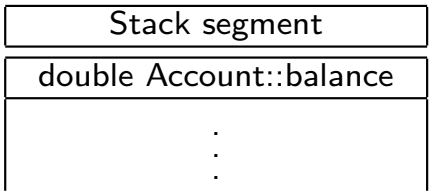
Stack segment
double Account::balance
CheckingAccount::total_fees
CheckingAccount::atm_fees
. . .

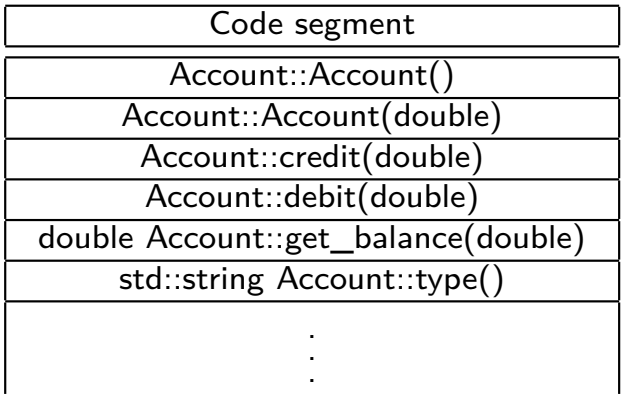
Code segment
Account::Account()
Account::Account(double)
Account::credit(double)
Account::debit(double)
double Account::get_balance(double)
std::string Account::type()
. . .

Code segment
Account::Account()
Account::Account(double)
Account::credit(double)
Account::debit(double)
double Account::get_balance(double)
std::string Account::type()
CheckingAccount::CheckingAccount(double, double)
CheckingAccount::cash_withdrawal(double)
double CheckingAccount::get_total_fees()
std::string CheckingAccount::type()
. . .

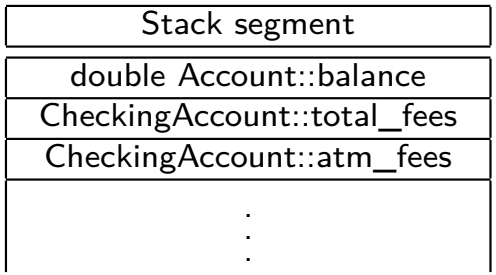
C++ classes: Inheritance - casting (object slicing)

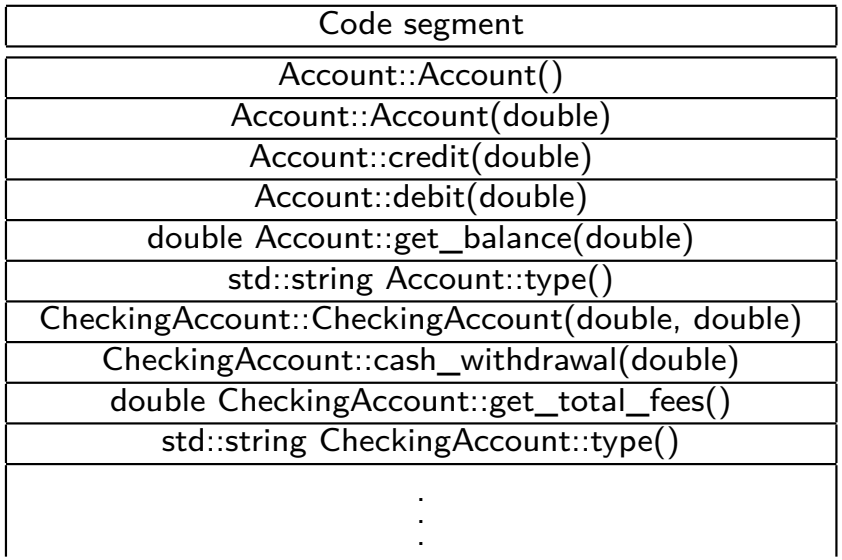
Base class:





Derived class:





* When the compiler lays out a derived object in memory, it puts the data of the base class first * We can cast a derived class to its base class * The compiler **slices out** the derived class, i.e. ignores the contents of memory past the base data

C++ classes: Inheritance - casting (object slicing)

Base class:

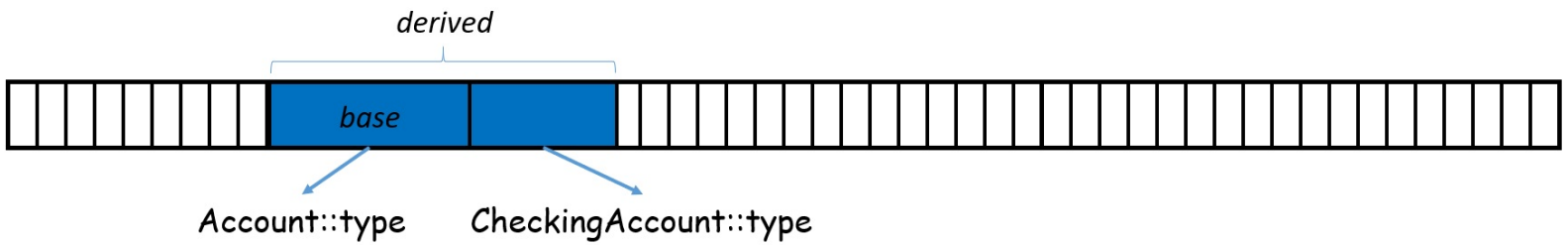
Stack segment
double Account::balance
. . .

Derived class:

Stack segment
double Account::balance
CheckingAccount::total_fees
CheckingAccount::atm_fees
. . .

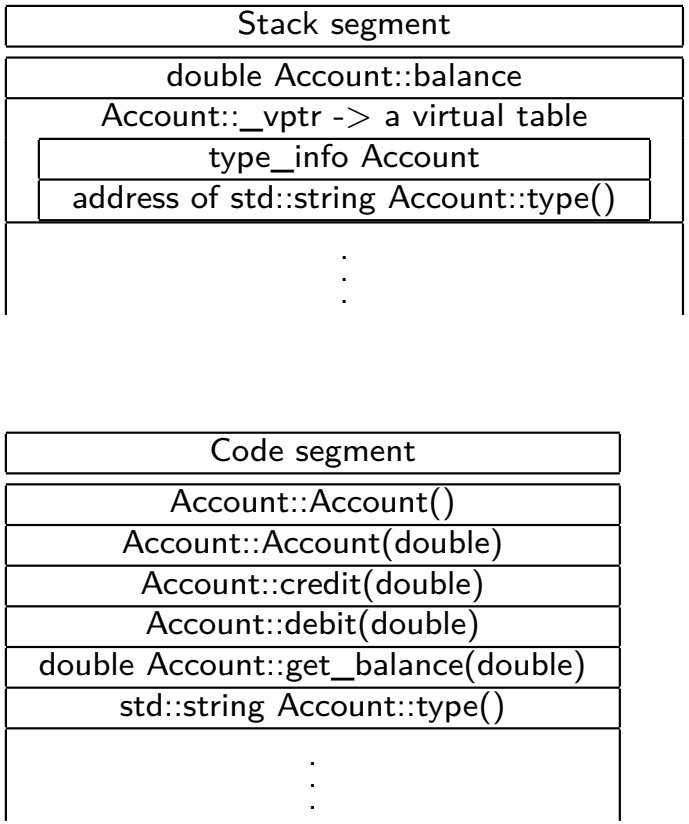
Code segment
Account::Account()
Account::Account(double)
Account::credit(double)
Account::debit(double)
double Account::get_balance(double)
std::string Account::type()
. . .

Code segment
Account::Account()
Account::Account(double)
Account::credit(double)
Account::debit(double)
double Account::get_balance(double)
std::string Account::type()
CheckingAccount::CheckingAccount(double, double)
CheckingAccount::cash_withdrawal(double)
double CheckingAccount::get_total_fees()
std::string CheckingAccount::type()
. . .



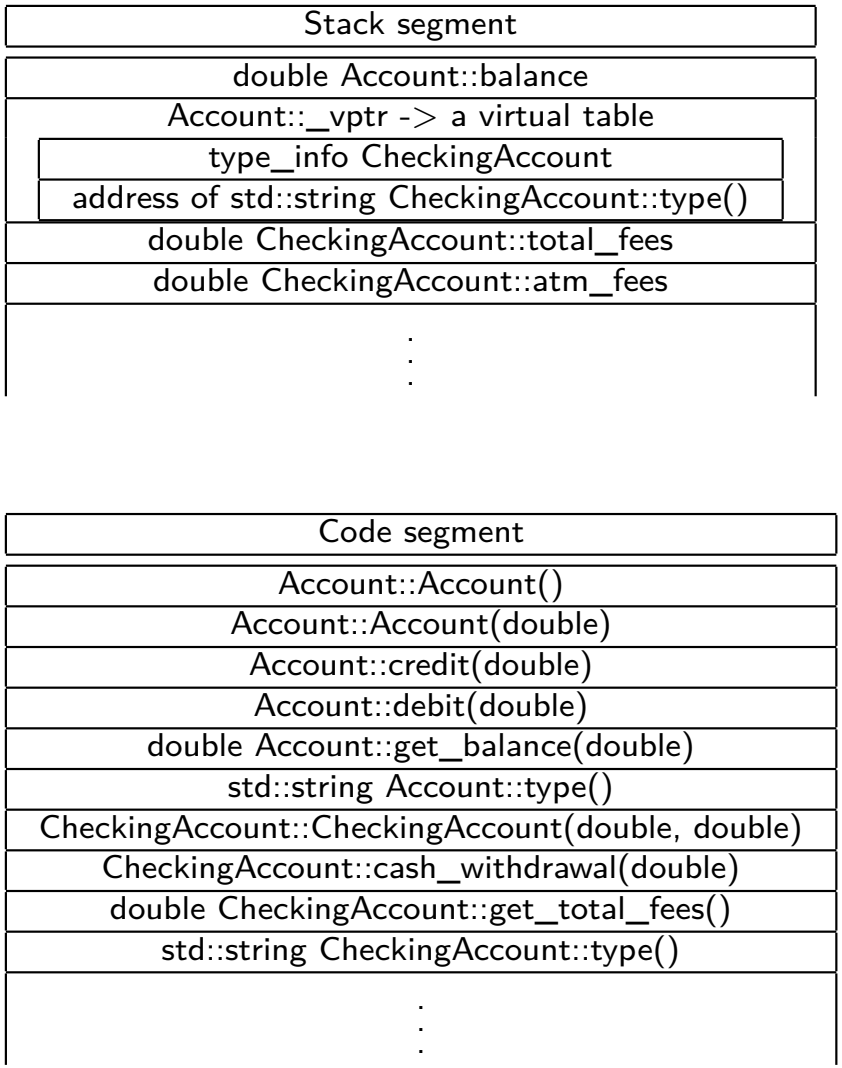
A brief memory layout of a class with `virtual` functions

```
class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial)
      : balance(initial) { }

    void credit(double amt) {
        balance += amt;
    }
    void debit(double amt) {
        balance -= amt;
    }
    double get_balance() const {
        return balance;
    }
    virtual std::string type() const {
        return "Account";
    }
private:
    double balance;
};
```



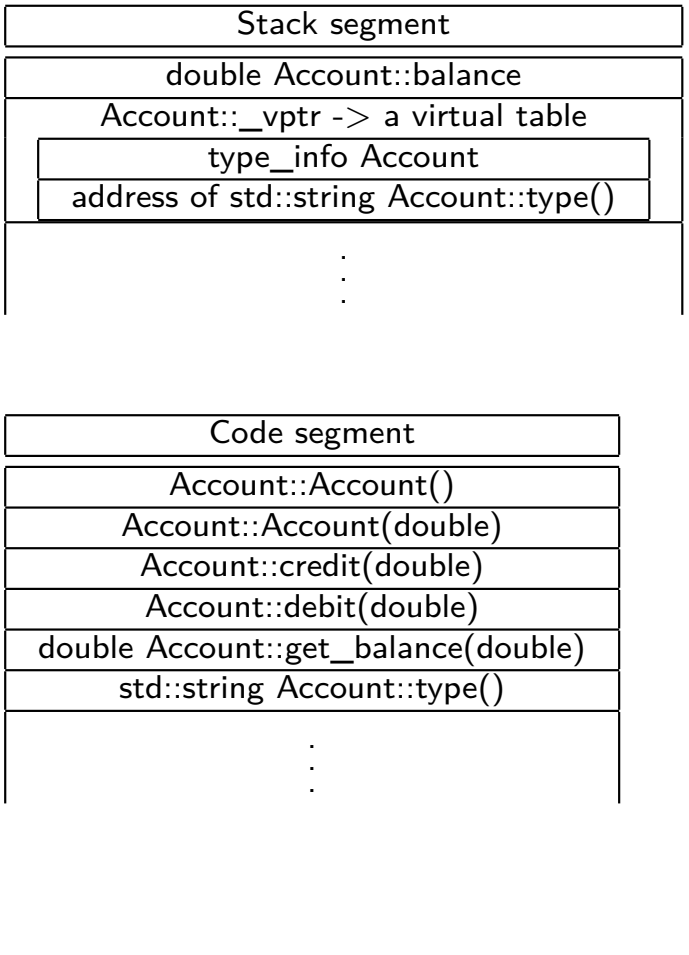
A brief memory layout of a simple derived class

```
class CheckingAccount : public Account {
public:
    CheckingAccount(double initial, double atm) :
    Account(initial), total_fees(0.0),
    atm_fee(atm) { }
    void cash_withdrawal(double amt) {
        total_fees += atm_fee;
        debit(amt + atm_fee);
    }
    double get_total_fees() const {
        return total_fees;
    }

    std::string type() const {
        return "CheckingAccount";
    }

private:
    double total_fees;
    double atm_fee;
};
```

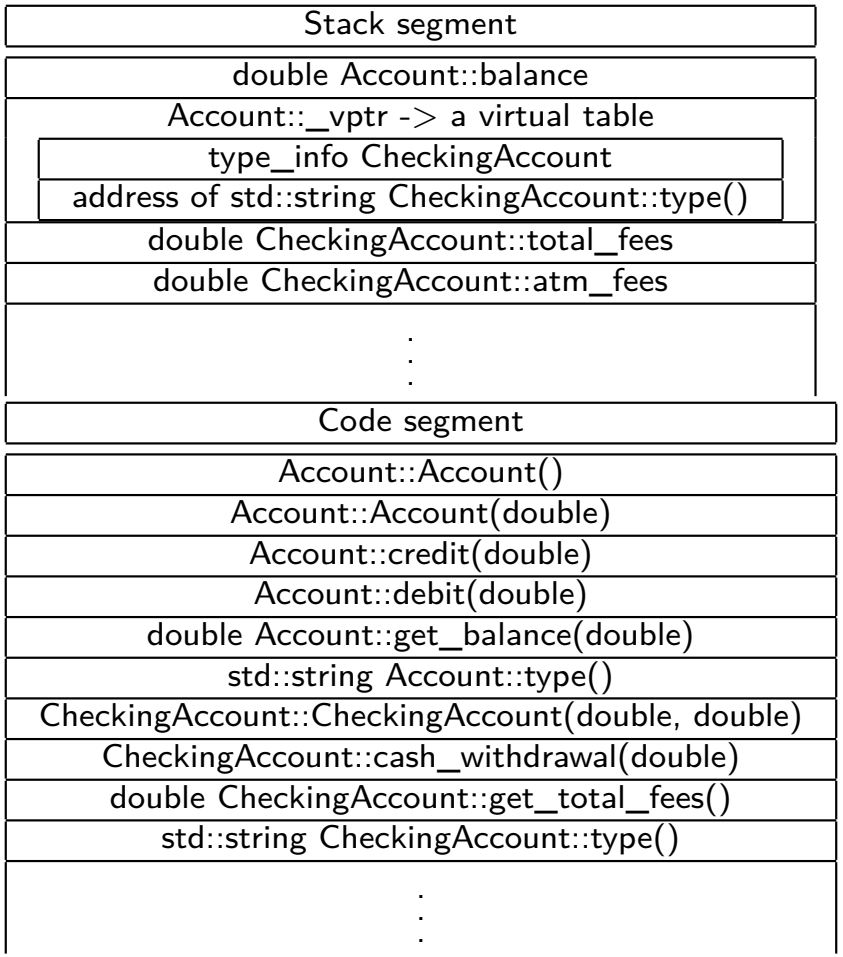


C++ classes: Inheritance - `virtual` (dynamic dispatch)

Base class:



Derived class:



- Use the keyword `virtual` to indicate that a method may be overridden by a derived class

C++ classes: Inheritance - `virtual` (dynamic dispatch)

What if the derived class has not overridden the virtual function?

```
// account3.cpp:
#include <iostream>
#include <string>

class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial) : balance(initial) { }

    void credit(double amt)    { balance += amt; }
    void debit(double amt)     { balance -= amt; }
    double get_balance() const { return balance; }
    virtual std::string type() const
    { return "Account"; }
private:
    double balance;
};

class CheckingAccount : public Account {
public:
    CheckingAccount(double initial, double atm) :
    Account(initial), total_fees(0.0),
    atm_fee(atm) { }
    void cash_withdrawal(double amt) {
        total_fees += atm_fee;
        debit(amt + atm_fee);
    }
    double get_total_fees() const {
        return total_fees;
    }

private:
    double total_fees;
    double atm_fee;
};


void print_account_type(const Account& acct) {
    std::cout << acct.type() << std::endl;
}

int main() {
    Account acct(1000.0);
    CheckingAccount checking(1000.0, 2.00);
    print_account_type(acct);
    print_account_type(checking);
    return 0;
}
```

C++ classes: Inheritance - `virtual` (dynamic dispatch)

```
$ g++ -c account3.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o account3 account3.o
$ ./account3
Account
Account
```

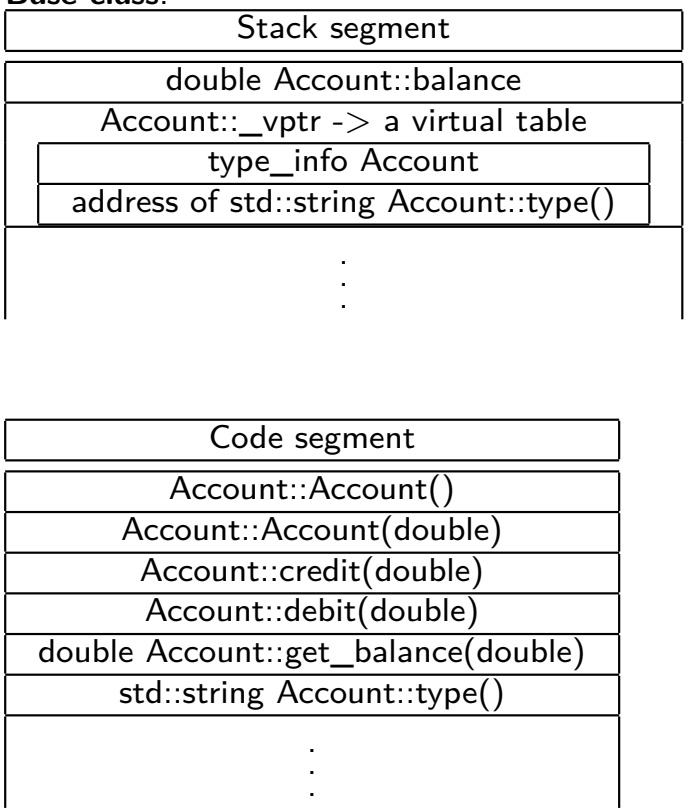
No compilation error!

The virtual table (dynamic dispatch) uses the base class's implementation by default (if the derived class doesn't have one).

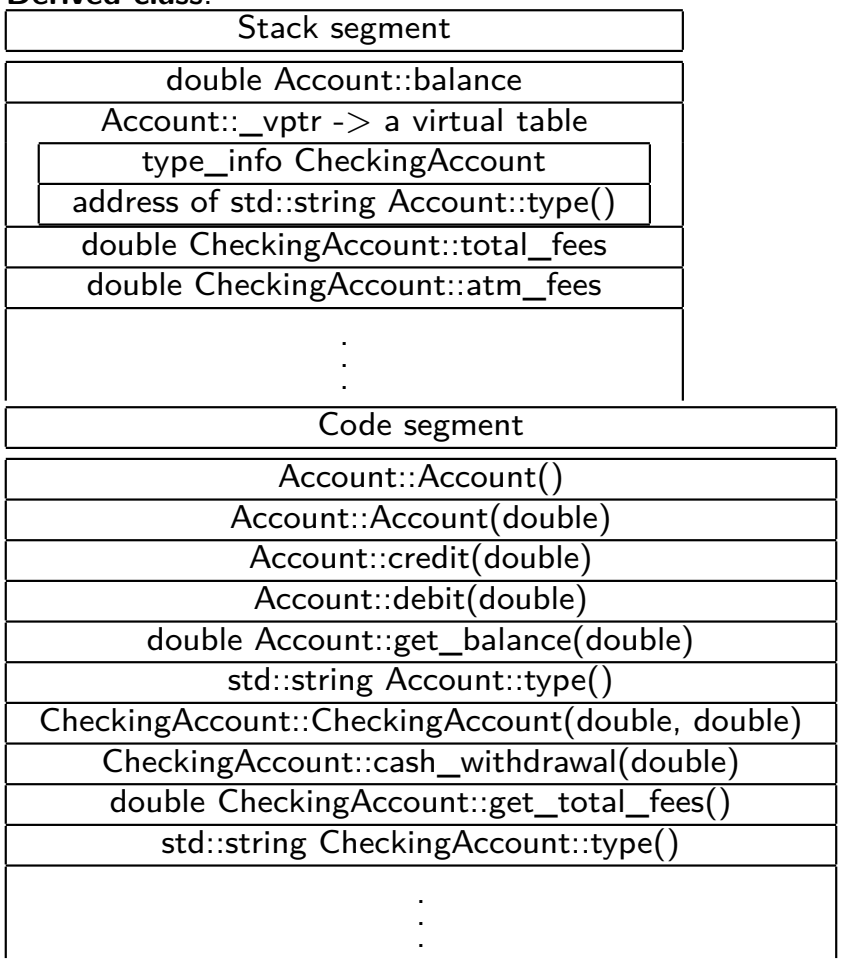
C++ classes: Inheritance - `virtual` (dynamic dispatch)

In this case, the memory layouts look like:

Base class:



Derived class:



The keyword `override`

Even worse is we believe we have overriden the ‘virtual function:

```
#include <iostream>
#include <string>

using std::cout; using std::endl;

class Account {
public:
   virtual std::string type() const { return "Account"; }
};

class CheckingAccount : public Account {
public:
   virtual std::string type() { return "CheckingAccount"; }
};

int main() {
   CheckingAccount checking;
   Account& acct = checking;
   cout << acct.type() << endl; // polymorphism?
   return 0;
}
```

The keyword `override`

```
$ g++ -c override.cpp -std=c++11 -pedantic -Wall -Wextra $ g++ -o
override override.o $ ./override Account
```

Sometimes you intend to override a function in the base class. . .

. . . but you fail

The keyword `override`

In this case, it was just a matter of missing a const

```
class Account {
public:
   virtual std::string type() const { return "Account"; }
   //                         ^^^^^ oops
};

class CheckingAccount : public Account {
public:
   virtual std::string type() { return "CheckingAccount"; }
   //                        ^^ missed const
};
```

The keyword `override`

- This is a typical mistake, often because we:
  - fail to match const status
  - fail to exactly match parameter & return types
- The `override` keyword helps
- When you intend to override a function, add the override modifier:

```
class Account {
public:
   virtual std::string type() const { return "Account"; }
};

class CheckingAccount : public Account {
public:
   virtual std::string type() override { return "CheckingAccount"; }
   //                         ^^^ use override in derived class
};
```

The keyword `override`

```
#include <iostream>
#include <string>

using std::cout; using std::endl;

class Account {
public:
   virtual std::string type() const { return "Account"; }
};

class CheckingAccount : public Account {
public:
   virtual std::string type() override { return "CheckingAccount"; }
};

int main() {
   CheckingAccount checking;
   Account& acct = checking;
   cout << acct.type() << endl; // dynamic dispatch?
   return 0;
}
```

```
$ g++ -c override3.cpp -std=c++11 -pedantic -Wall -Wextra
override3.cpp:14:24: error: ‘virtual std::string CheckingAccount::type()’ marked ‘override’, but does not
   14 |    virtual std::string type() override { return "CheckingAccount"; }
      |                        ^~~~
```

The keyword `override`

Now we combine it with const to fix the problem:

```
class Account {
public:
   virtual std::string type() const { return "Account"; }
};

class CheckingAccount : public Account {
public:
   virtual std::string type() const override { return "CheckingAccount"; }
};
```

The keyword override

```
#include <iostream>
#include <string>

using std::cout; using std::endl;

class Account {
public:
   virtual std::string type() const { return "Account"; }
};

class CheckingAccount : public Account {
public:
   virtual std::string type() const override { return "CheckingAccount"; }
};

int main() {
   CheckingAccount checking;
   Account& acct = checking;
   cout << acct.type() << endl; // polymorphism?
   return 0;
}
```

```
$ g++ -c override_fix.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o override_fix override_fix.o
$ ./override_fix
CheckingAccount
```

Pass by-value vs by-reference

What happens if we forget to pass by-reference?

```
#include <iostream>
#include <string>

using std::cout;  using std::endl;

class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial) : balance(initial) { }

    void credit(double amt)    { balance += amt; }
    void debit(double amt)     { balance -= amt; }
    double get_balance() const { return balance; }
    virtual std::string type() const { return "Account"; }
private:
    double balance;
};

class CheckingAccount : public Account {
public:
    CheckingAccount(double initial, double atm) :
        Account(initial), total_fees(0.0),
            atm_fee(atm) { }
    void cash_withdrawal(double amt) {
        total_fees += atm_fee;
        debit(amt + atm_fee);
    }
    double get_total_fees() const {
        return total_fees;
    }

    virtual std::string type() const {
        return "CheckingAccount";
    }

private:
    double total_fees;
    double atm_fee;
};

void print_account_type(const Account acct) {
    cout << acct.type() << endl;
}

int main() {
    Account acct(1000.0);
    CheckingAccount checking(1000.0, 2.00);
    print_account_type(acct);
    print_account_type(checking);
    return 0;
}
```

Pass by-value vs by-reference

It won't work! Why?

```
$ g++ -c account2.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o account2 account2.o
$ ./account2
Account
Account
```

Recall: when passing by-value, **copy constructor** is called to create a copy of the passing object. The copy constructor takes a reference of the passing object as its input (so object slicing does happen when calling the constructor), but the newly created object (inside the constructor scope) is using the base class memory layout, which means the virtual function is pointing to `Account::type()`.