Dynamic dispatch

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

The Account example w/o virtual

```
// acc.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; }
  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) {
  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;
}
```

The `Account` example w/o `virtual`

```
$ g++ -o acc acc.cpp -std=c++11 -pedantic -Wall -Wextra

$ ./acc

Account
Account
```

It doesn't work without `virtual`.

The Account example using virtual

```
// acc_vt.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;
  }

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

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;
}
```

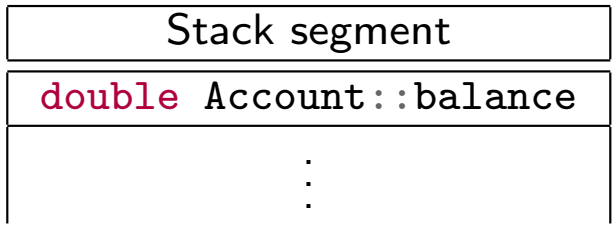
The `Account` example using `virtual`

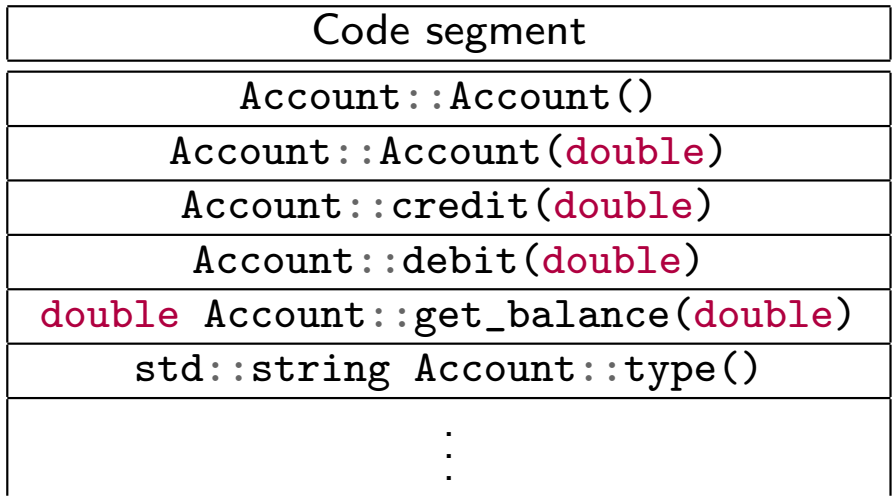
```
$ g++ -o acc_vt acc_vt.cpp -std=c++11 -pedantic -Wall -Wextra

$ ./acc_vt

Account
CheckingAccount
```

But how does it work internally in C++?

A brief memory layout of a simple class

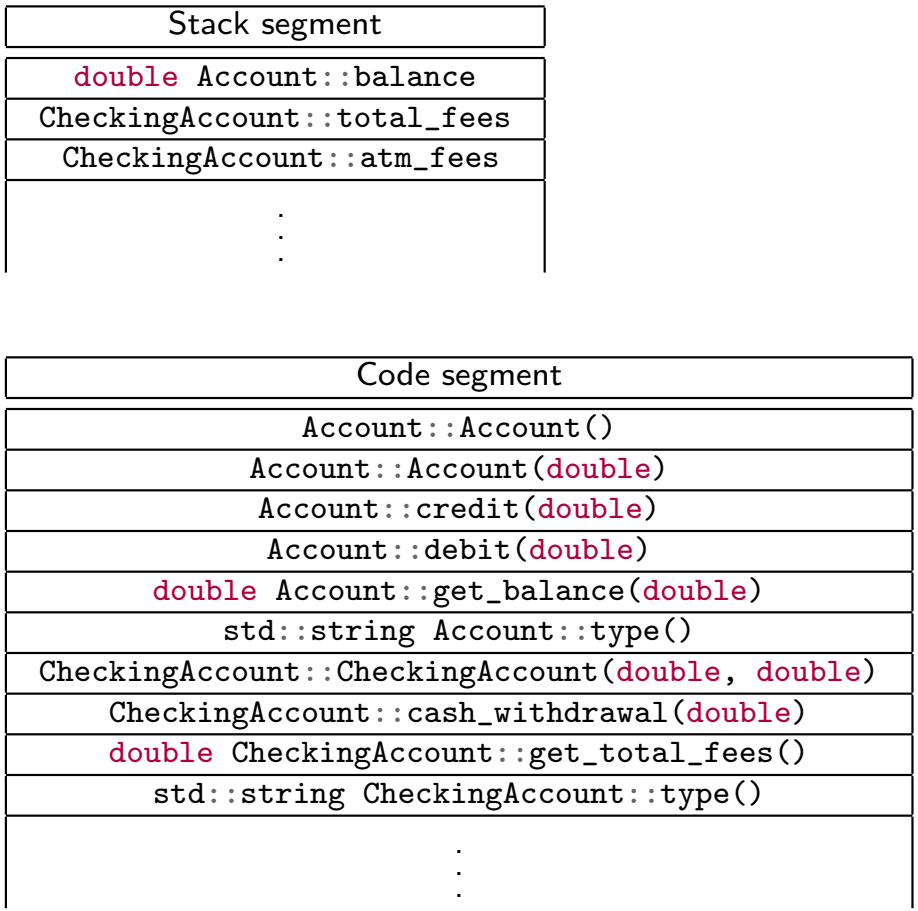
```
class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial)
      : balance(initial) { }

    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`
⋮

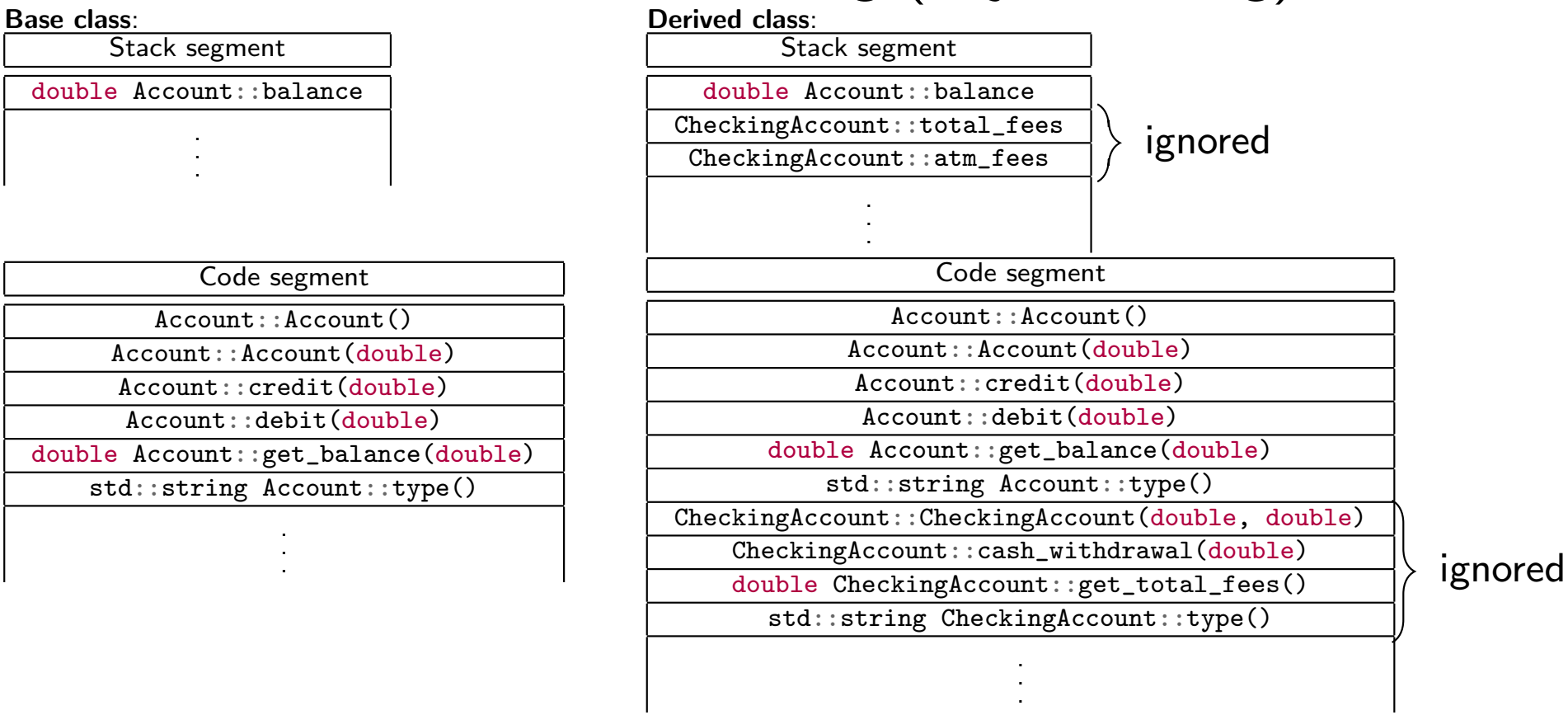
Derived class:

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()`
⋮

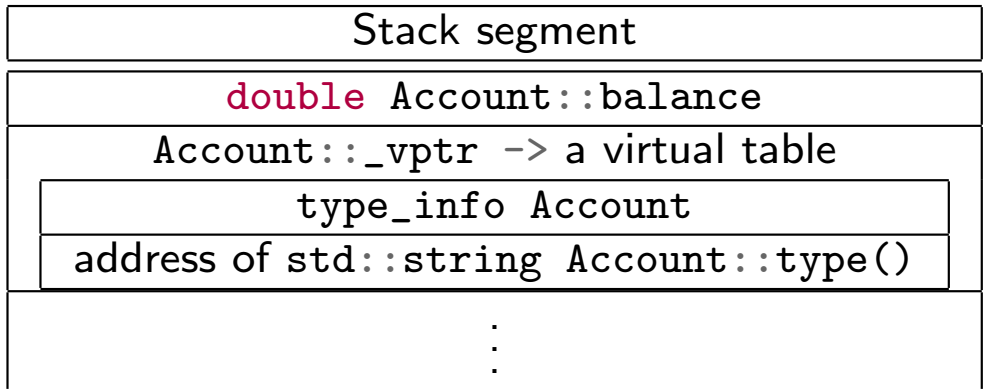
C++ classes: Inheritance - casting (object slicing)

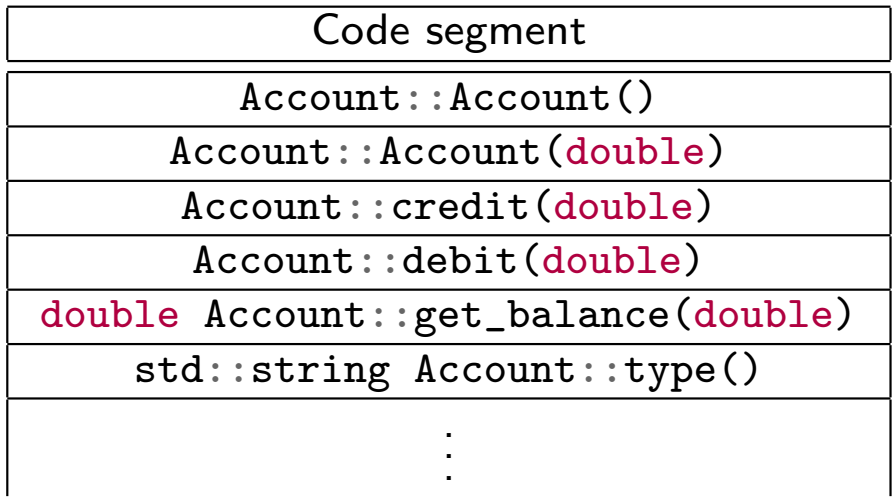


- When the compiler lays out a derived object in memory, it puts the data of the base class first
- We can convert from a derived class back to its base
  - The compiler **slices out** the derived class, i.e. ignores the contents of memory past the base data;

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

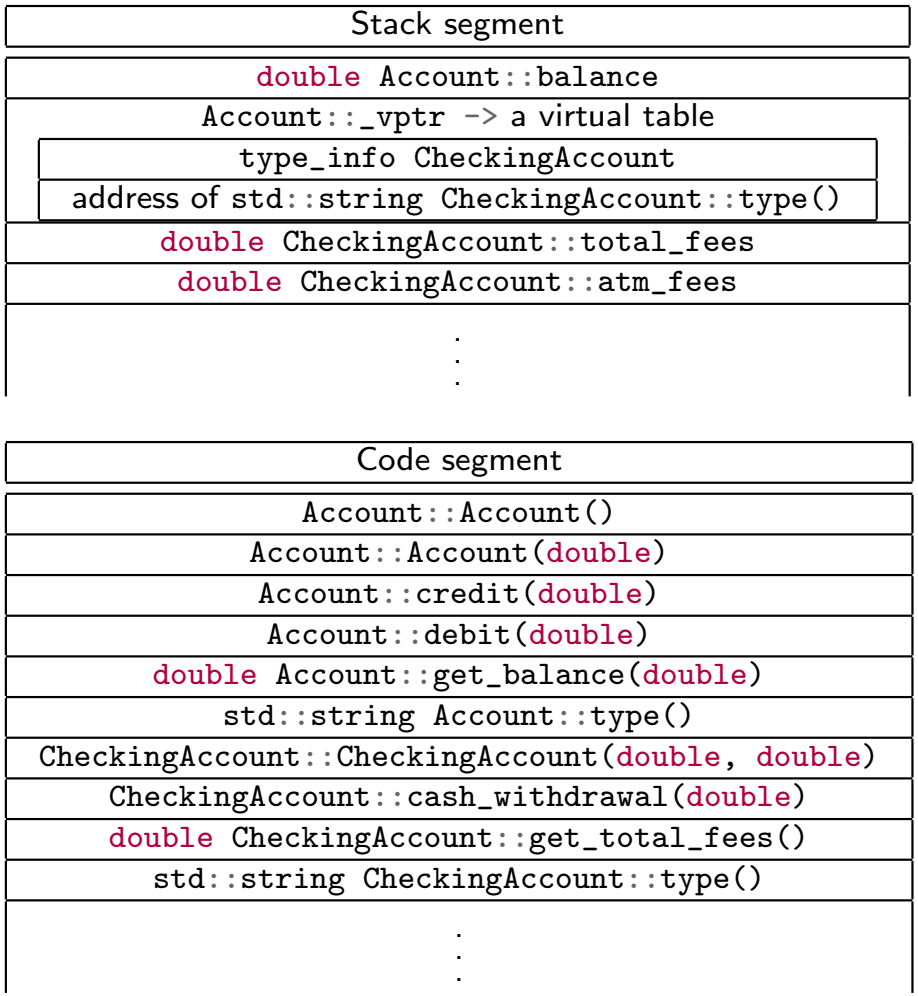
```
class Account {
public:
    Account() : balance(0.0) { }
    Account(double initial)
      : balance(initial) { }

    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;
};
```





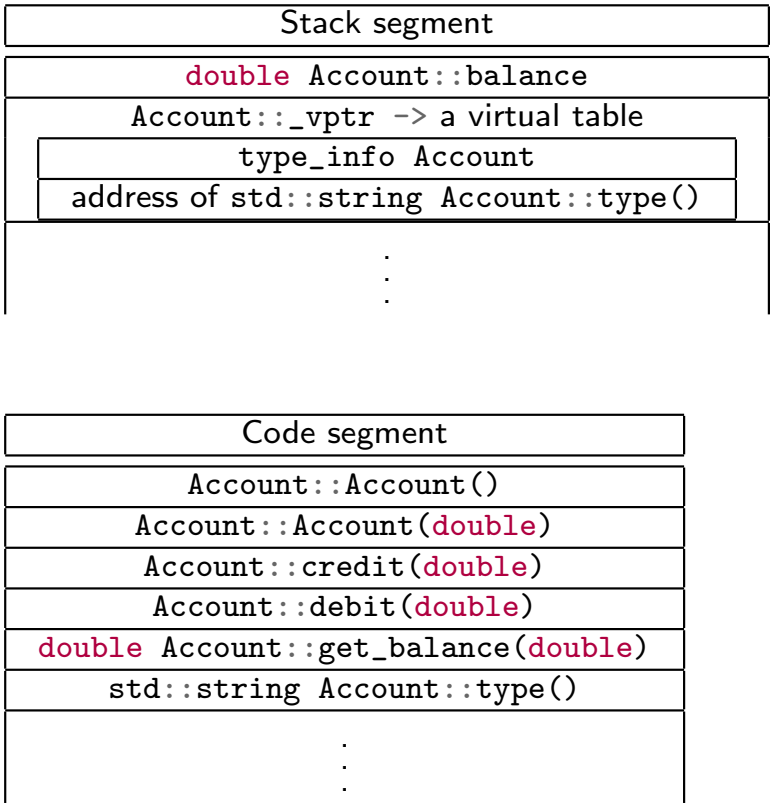
A brief memory layout of a simple derived class

```
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;
};
```

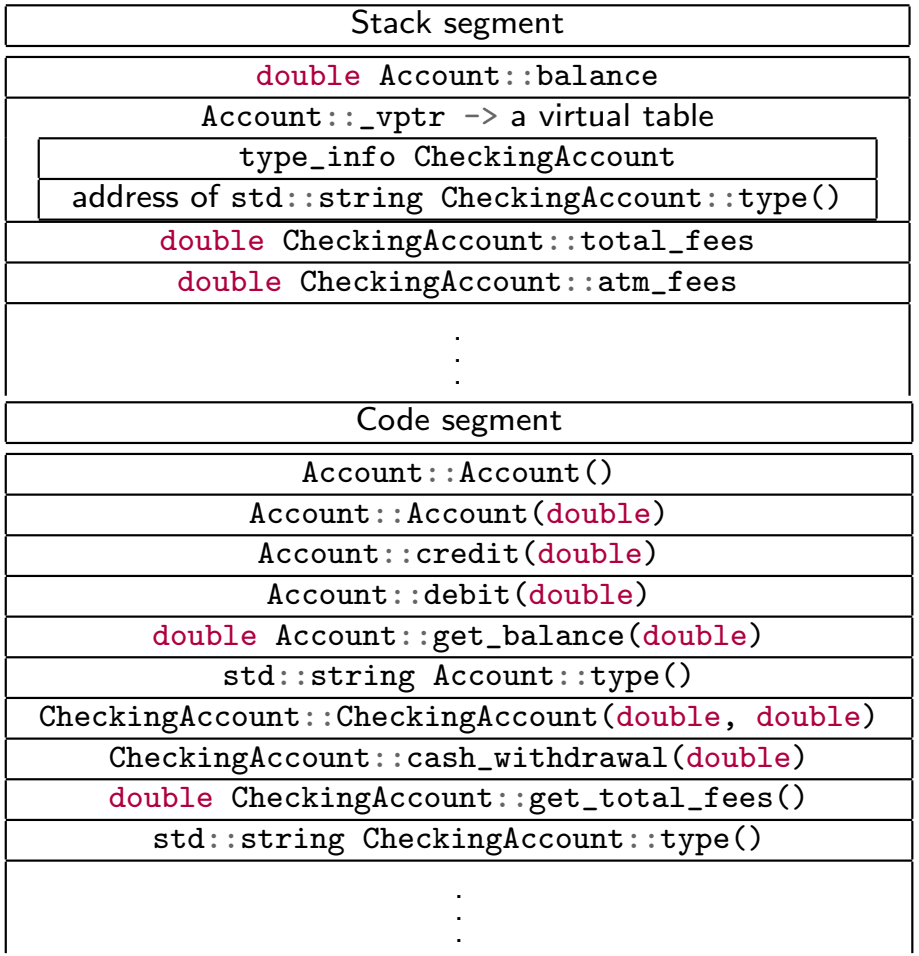


C++ classes: Inheritance - `virtual` (dynamic dispatch)

Base class:



Derived class:



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

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

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

```
// acc_vt2.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++ -o acc_vt2 acc_vt2.cpp -std=c++11 -pedantic -Wall -Wextra

$ ./acc_vt2

Account
Account
```

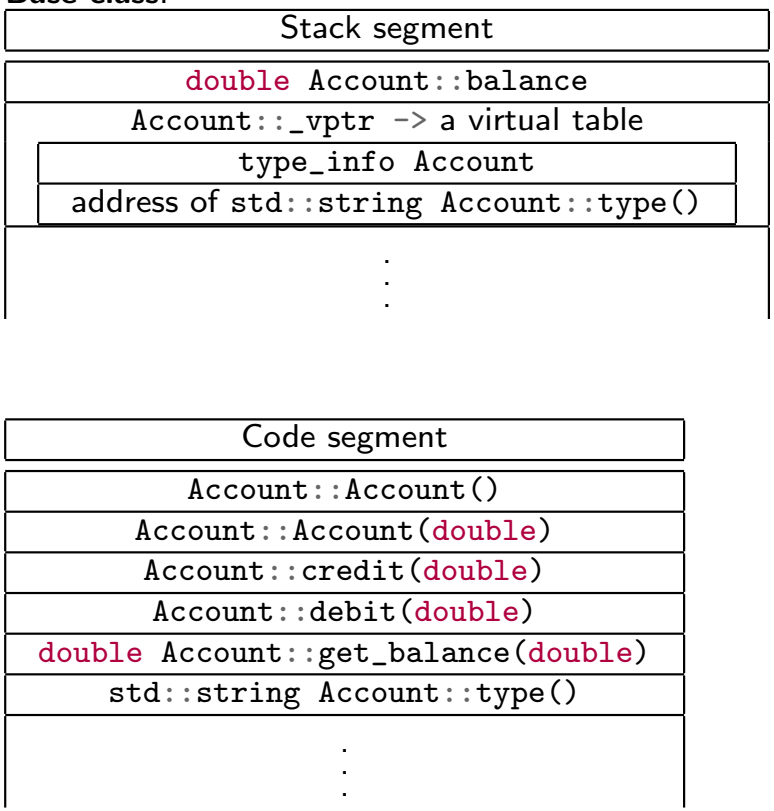
No compilation error!

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

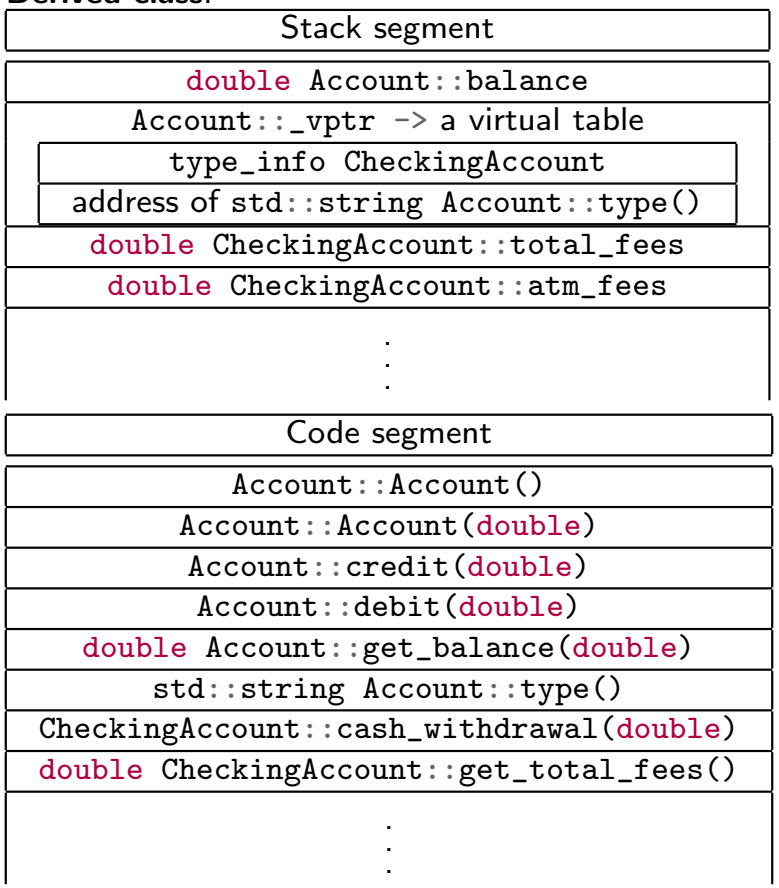
C++ classes: Inheritance - `virtual` (dynamic dispatch)

In this case, the memory layouts look like:

Base class:



Derived class:



The keyword `override`

Even worse is we believe we have overridden the virtual function:

```
// override.cpp

#include <iostream>
#include <string>

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

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

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

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

$ ./override

Account
```

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:
    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 parameters & return types
- The keyword `override` 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:
    std::string type() override { return "CheckingAccount"; }
        //                ^^ use override in derived class
};
```

The keyword override

```
// override2.cpp
#include <iostream>
#include <string>

class Account {
public:
    virtual std::string type() const { return "Account"; }
};
class CheckingAccount : public Account {
public:
    std::string type() override { return "CheckingAccount"; }
};
int main() {
    CheckingAccount checking;
    Account& acct = checking;
    std::cout << acct.type() << std::endl; // dynamic dispatch?
    return 0;
}
```

```
$ g++ -o override2 override2.cpp -std=c++11 -pedantic -Wall -Wextra

override2.cpp:10:17: error: std::__cxx11::string CheckingAccount::type() marked override, but does not ove
     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:
    std::string type() const override { return "CheckingAccount"; }
};
```

The keyword override

```
// override3.cpp
#include <iostream>
#include <string>

class Account {
public:
    virtual std::string type() const { return "Account"; }
};
class CheckingAccount : public Account {
public:
    std::string type() const override { return "CheckingAccount"; }
};
int main() {
    CheckingAccount checking;
    Account& acct = checking;
    std::cout << acct.type() << std::endl; // dynamic dispatch?
    return 0;
}
```

```
$ g++ -o override3 override3.cpp -std=c++11 -pedantic -Wall -Wextra
$ ./override3
CheckingAccount
```

Pass by-value vs by-reference

What happens if we forget to pass by-reference?

```
// acc_vt3.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;
    }

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

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;
}
```

Pass by-value vs by-reference

It won't work! Why?

```
$ g++ -o acc_vt3 acc_vt3.cpp -std=c++11 -pedantic -Wall -Wextra
$ ./acc_vt3
Account
Account
```

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