Polymorphism

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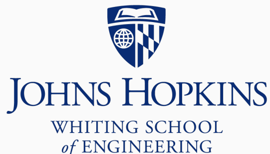


Source markdown available at github.com/BenLangmead/c-cpp-notes

Polymorphism

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

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

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

Polymorphism

```cpp
#include <iostream>
#include "account2.h"

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

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

int main() {
    Account acct(1000.0);
    CheckingAccount checking(1000.0, 2.00);
    SavingsAccount saving(1000.0, 0.05);

    print_account_type(acct);
    print_account_type(checking);
    print_account_type(saving);

    return 0;
}
```

Polymorphism

Note the types:

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

int main() {
    ...
    CheckingAccount checking(1000.0, 2.00);
    ...
    print_account_type(checking);
    ...
}
```

Polymorphism

In `main`, `checking_acct` has type `CheckingAccount`

Passed to `print_account_type` as `const Account&`; you may use a variable of a derived type *as though it has the base type*

- Makes sense: `CheckingAccount` *is a* `Account`

Polymorphism

```
int main() {
    vector<Account> my_accounts;

    // this is OK; CheckingAccount is
    // derived from Account
    my_accounts.push_back(CheckingAccount(2000.0));

    cout << my_accounts.back().type() << endl;
    return 0;
}
```

Polymorphism

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

int main() {
    ...
    CheckingAccount checking(1000.0, 2.00);
    ...
    print_account_type(checking_acct);
    ...
}
```

Does `acct.type()` call:

- `Account::type()` – the parameter's type?
- `CheckingAccount::type()` – checking's declared type?

Polymorphism

```
$ g++ -c account_main3.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o account_main3 account_main3.o
$ ./account_main3
Account
Account
Account
```

It calls `Account::type()`

What if we want the call the member corresponding to the *original declared* type of the variable (`CheckingAccount`) rather than the base type we happen to be using for it right now (`Account`)?

This requires *dynamic binding*

- Declare relevant member functions as *virtual*:

Polymorphism

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

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

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

Polymorphism

```cpp
#include <iostream>
#include "account3.h"  // now with *virtual* `type` member functions

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

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

int main() {
    Account acct(1000.0);
    CheckingAccount checking(1000.0, 2.00);
    SavingsAccount saving(1000.0, 0.05);

    print_account_type(acct);
    print_account_type(checking);
    print_account_type(saving);

    return 0;
}
```

Polymorphism

```
$ g++ -c account_main4.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o account_main4 account_main4.o
$ ./account_main4
Account
CheckingAccount
SavingsAccount
```

Dynamic binding / `virtual` functions enable C++ *polymorphism*

- In Java & Python *all methods are virtual*; you have no choice

A `class` object can look "on the surface" like the base class while behaving like the derived class

Polymorphism

```
#include <iostream>
#include "account3.h"  // still with *virtual* `type` member functions

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

// !!! *** Pass by value this time *** !!!
void print_account_type(Account acct) {
    cout << acct.type() << endl;
}

int main() {
    Account acct(1000.0);
    CheckingAccount checking(1000.0, 2.00);
    SavingsAccount saving(1000.0, 0.05);
    print_account_type(acct);
    print_account_type(checking);
    print_account_type(saving);
    return 0;
}
```

Polymorphism

```
$ g++ -c account_main5.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o account_main5 account_main5.o
$ ./account_main5
Account
Account
Account
```

Fields only in the derived class are simply not copied when passed by value using the base type

- This is *object slicing*

Passing by reference doesn't cause slicing and preserves our ability to call virtual functions in the derived class; another reason to prefer passing `class` variables by reference

Polymorphism

https://www.completelydelicious.com/cut-cake-even-layers/

Polymorphism

```
class Base {
public:
    void         normal();
    virtual void virt();
};
```

```
class Derived : public Base {
public:
    void         normal();
    virtual void virt();
};
```

Say we declare `Derived o` and later pass `o` to a function. The member functions called with `.normal()` and `.vert()` depend on the parameter type.

Param type	a.normal()	a.virt()	What happens?
Derived& a	Derived::normal()	Derived::virt()	Passed by ref
Derived a	Derived::normal()	Derived::virt()	Copied, not sliced
Base& a	Base::normal()	Derived::virt()	Passed by ref
Base a	Base::normal()	Base::virt()	Sliced & copied

Polymorphism

Same reasoning applies when converting between related types implicitly or using casting:

```
int main() {
    Derived original;

    // sliced; b.virt() -> Base::virt()
    Base b        = (Base)original;

    // reference; bref.virt() -> Derived::virt()
    Base& bref    = original;

    Derived d     = original;  // simple copy
    Derived& dref = original;  // simple reference

    return 0;
}
```

Polymorphism

Virtual functions allow a `class` variable to remember and act like its declared type even when temporarily taking the base type

- . . . but *how* do they remember?

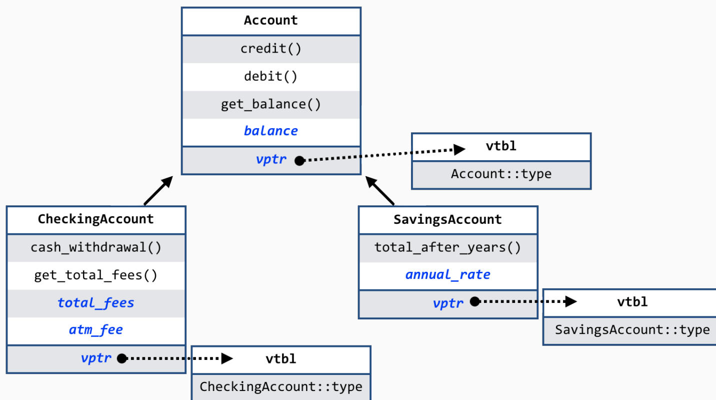
When a class has a virtual member function, it also gets a hidden *virtual function table* or *vtable*

- Points to declared-type implementation

Table adds 1 pointer (8 bytes) to size of `class`, regardless of number of virtual functions

Polymorphism

Blue-highlighted items take memory in `class` variables. Memory is also needed for function code and virtual-function tables (`vtbls`), but those aren't per-object, and `sizeof` won't include them.



Polymorphism

Sometimes the base class is too generic to be useful as much more than a “guide” for derived classes

```
class Shape {
public:
    virtual double area() const { } // NO SENSIBLE IMPLEMENTATION FOR THIS
};

class Rectangle : public Shape {
public:
    ...
    virtual double area() const { return width * height; }
    ...
private:
    double width, height;
};

class Circle : public Shape {
public:
    ...
    virtual double area() const { return PI * radius * radius; }
    ...
private:
    double radius;
};
```

Polymorphism

We use *pure virtual* functions to flag member functions that *cannot* be usefully implemented in the base class and *must* be overridden and implemented in a derived class

```
class Shape {
public:
    virtual double area() const = 0; // pure virtual
};
```

A class with any *pure virtual* functions is an *abstract base class*

- You may not instantiate an abstract base class
- E.g. `Shape s;` is not allowed; use derived type(s) instead

Polymorphism

```
#include <iostream>

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

class Shape {
public:
    virtual double area() const = 0;
};

class Rectangle : public Shape {
public:
    Rectangle(double w, double h) : width(w), height(h) { }
    virtual double area() const { return width * height; }
private:
    double width, height;
};

int main() {
    Shape s;
    Rectangle r = {10.0, 5.0};
    cout << "r area = " << r.area() << endl;
    return 0;
}
```

Polymorphism

```
$ g++ -c shapes.cpp -std=c++11 -pedantic -Wall -Wextra
shapes.cpp: In function 'int main()':
shapes.cpp:19:11: error: cannot declare variable 's' to be of abstract type
'Shape'
     Shape s;
           ^
shapes.cpp:5:7: note:   because the following virtual functions are pure within
'Shape':
 class Shape {
       ^~~~~
shapes.cpp:7:20: note:  virtual double Shape::area() const
     virtual double area() const = 0;
                    ^~~~
```

Polymorphism

```
#include <iostream>

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

class Shape {
public:
    virtual double area() const = 0;
};

class Rectangle : public Shape {
public:
    Rectangle(double w, double h) : width(w), height(h) { }
    virtual double area() const { return width * height; }
private:
    double width, height;
};

int main() {
    // Shape s;  // **** got rid of this *****
    Rectangle r = {10.0, 5.0};
    cout << "r area = " << r.area() << endl;
    return 0;
}
```

Polymorphism

```
$ g++ -c shapes.cpp -std=c++11 -pedantic -Wall -Wextra
$ g++ -o shapes shapes.o
$ ./shapes
r area = 50
```

Polymorphism

`virtual` syntax details:

- Omit `virtual` keyword when defining a `virtual` member function outside a `class` definition
- When declaring a `virtual` member function that overrides one in the parent class, you *may* omit the `virtual` keyword
- When you declare a `virtual` member function that should override one in the base class, use the `override` keyword
  - Helps catch mistakes where you intended to override but failed to due to a minor difference in function signature