Section Overview

Inheritance

- What is Inheritance?
  - Why is it useful?
- Terminology and Notation
- Inheritance vs. Composition
- Deriving classes from existing classes
  - Types of inheritance
- Protected members and class access
- Constructors and Destructors
  - Passing arguments to base class constructors
  - Order of constructor and destructors calls
- Redefining base class methods
- Class Hierarchies
- Multiple Inheritance

Inheritance

What is it and why is it used?

- Provides a method for creating new classes from existing classes
- The new class contains the data and behaviors of the existing class
- Allow for reuse of existing classes
- Allows us to focus on the common attributes among a set of classes
- Allows new classes to modify behaviors of existing classes to make it unique
  - Without actually modifying the original class

Inheritance

Related classes

- Player, Enemy, Level Boss, Hero, Super Player, etc.
- Account, Savings Account, Checking Account, Trust Account, etc.
- Shape, Line, Oval, Circle, Square, etc.
- Person, Employee, Student, Faculty, Staff, Administrator, etc.

Inheritance

Accounts

- Account
  - **balance**, **deposit**, **withdraw**, . . .
- Savings Account
  - **balance**, **deposit**, **withdraw**, interest rate, . . .
- Checking Account
  - **balance**, **deposit**, **withdraw**, minimum balance, per check fee, . . .
- Trust Account
  - **balance**, **deposit**, **withdraw**, interest rate, . . .

Inheritance

Accounts – without inheritance – code duplication

```
class Account {
    // balance, deposit, withdraw, . . .
};

class Savings_Account {
    // balance, deposit, withdraw, interest rate, . . .
};

class Checking_Account {
    // balance, deposit, withdraw, minimum balance, per check fee, . . .
};

class Trust_Account {
    // balance, deposit, withdraw, interest rate, . . .
};
```

Inheritance

Accounts – with inheritance – code reuse

```
class Account {
    // balance, deposit, withdraw, . . .
};

class Savings_Account : public Account {
    // interest rate, specialized withdraw, . . .
};

class Checking_Account : public Account {
    // minimum balance, per check fee, specialized withdraw, . . .
};

class Trust_Account : public Account {
    // interest rate, specialized withdraw, . . .
};
```

Inheritance

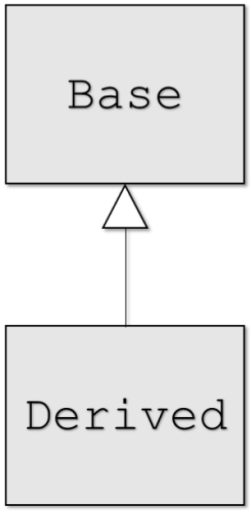
Terminology

- Inheritance
  - Process of creating new classes from existing classes
  - Reuse mechanism
- Single Inheritance
  - A new class is created from another ‘single’ class
- Multiple Inheritance
  - A new class is created from two (or more) other classes

Inheritance

Terminology

- Base class (parent class, super class)
  - The class being extended or inherited from
- Derived class (child class, sub class)
  - The class being created from the Base class
  - Will inherit attributes and operations from Base class



Inheritance

Terminology

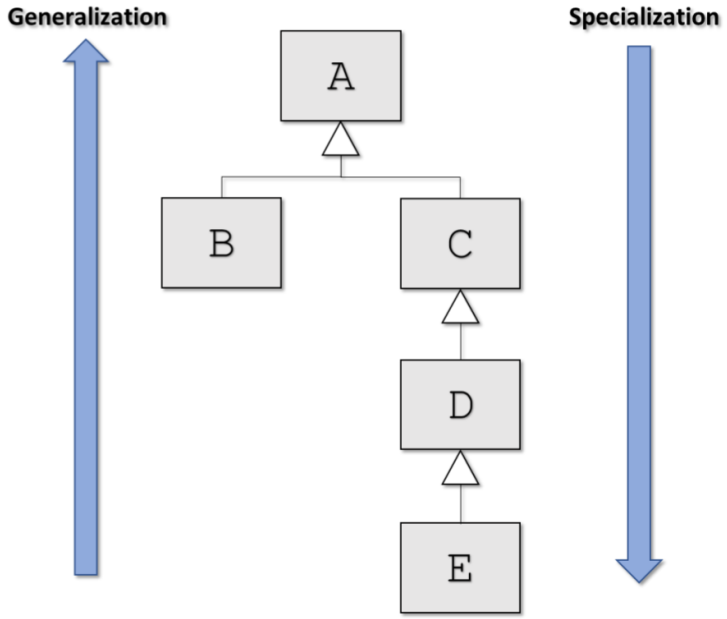
- "Is-A" relationship
  - Public inheritance
  - Derived classes are sub-types of their Base classes
  - Can use a derived class object wherever we use a base class object
- Generalization
  - Combining similar classes into a single, more general class based on common attributes
- Specialization
  - Creating new classes from existing classes proving more specialized attributes or operations
- Inheritance or Class Hierarchies
  - Organization of our inheritance relationships

Inheritance

Class hierarchy

Classes:

- A
- B is derived from A
- C is derived from A
- D is derived from C
- E is derived from D

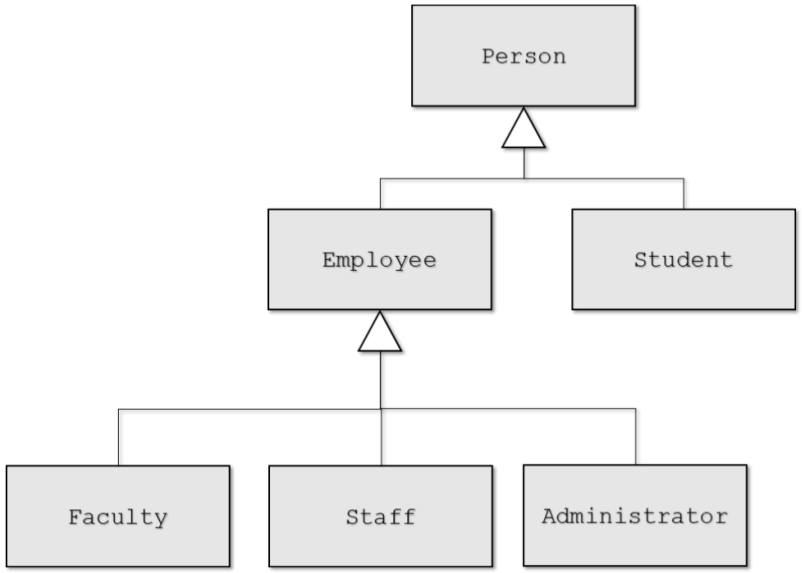


Inheritance

Class hierarchy

Classes:

- Person
- Employee is derived from Person
- Student is derived from Person
- Faculty is derived from Employee
- Staff is derived from Employee
- Administrator is derived from Employee



Inheritance

Public Inheritance vs. Composition

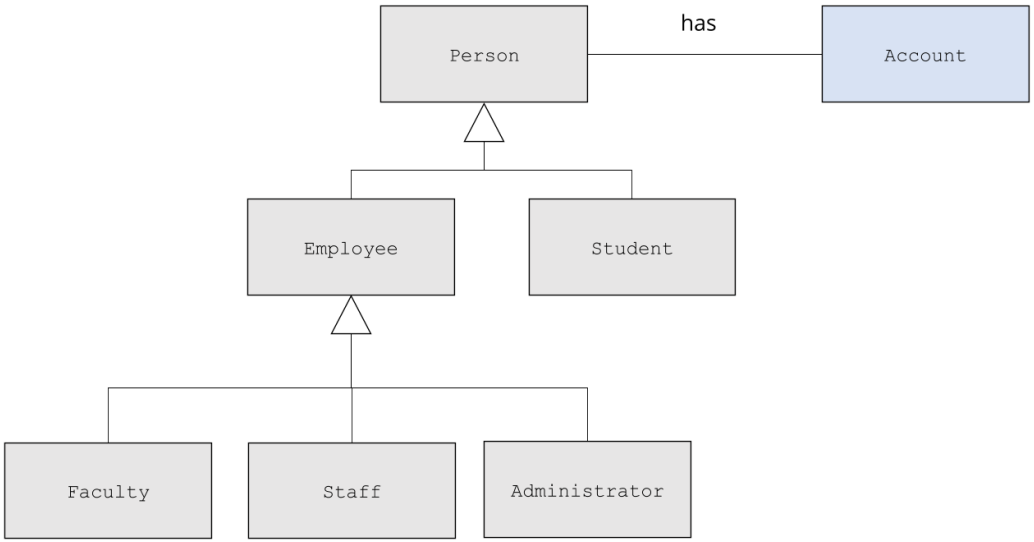
- Both allow reuse of existing classes

- Public Inheritance
  - "is-a" relationship
    - Employee 'is-a' Person
    - Checking Account 'is-a' Account
    - Circle "is-a" Shape

- Composition
  - "has-a" relationship
    - Person "has a" Account
    - Player "has-a" Special Attack
    - Circle "has-a" Location

Inheritance

Public Inheritance vs. Composition



Inheritance

Public Inheritance vs. Composition

```
class Person {
private:
    std::string name;  // has-a name
    Account account; // has-a account
};
```

Deriving classes from exiting classes

C++ derivation syntax

```
class Base {
  // Base class members . . .
};

class Derived: access-specifier Base {
   // Derived class members . . .
};
```

Access-specifier can be: `public`, `private`, or `protected`

Deriving classes from exiting classes

Types of inheritance in C++

- `public`
  - Most common
  - Establishes '**is-a**' relationship between Derived and Base classes

- `private` and `protected`
  - Establishes "derived class **has a** base class" relationship
  - "Is implemented in terms of" relationship
  - Different from composition

Deriving classes from exiting classes

C++ derivation syntax

```
class Account {
  // Account class members . . .
};

class Savings_Account: public Account {
   // Savings_Account class members . . .
};
```

`Savings_Account` 'is-a' `Account`

Deriving classes from exiting classes

C++ creating objects

```
Account account {};
Account *p_account = new Account();

account.deposit(1000.0);
p_account->withdraw(200.0);

delete p_account;
```

Deriving classes from exiting classes

C++ creating objects

```
Savings_Account sav_account {};
Savings_Account *p_sav_account = new Savings_Account();

sav_account.deposit(1000.0);
p_sav_account->withdraw(200.0);

delete p_sav_account;
```

Protected Members and Class Access

The protected class member modifier

```
class Base {

  protected:
    // protected Base class members . . .
};
```

- Accessible from the Base class itself
- Accessible from classes Derived from Base
- Not accessible by objects of Base or Derived

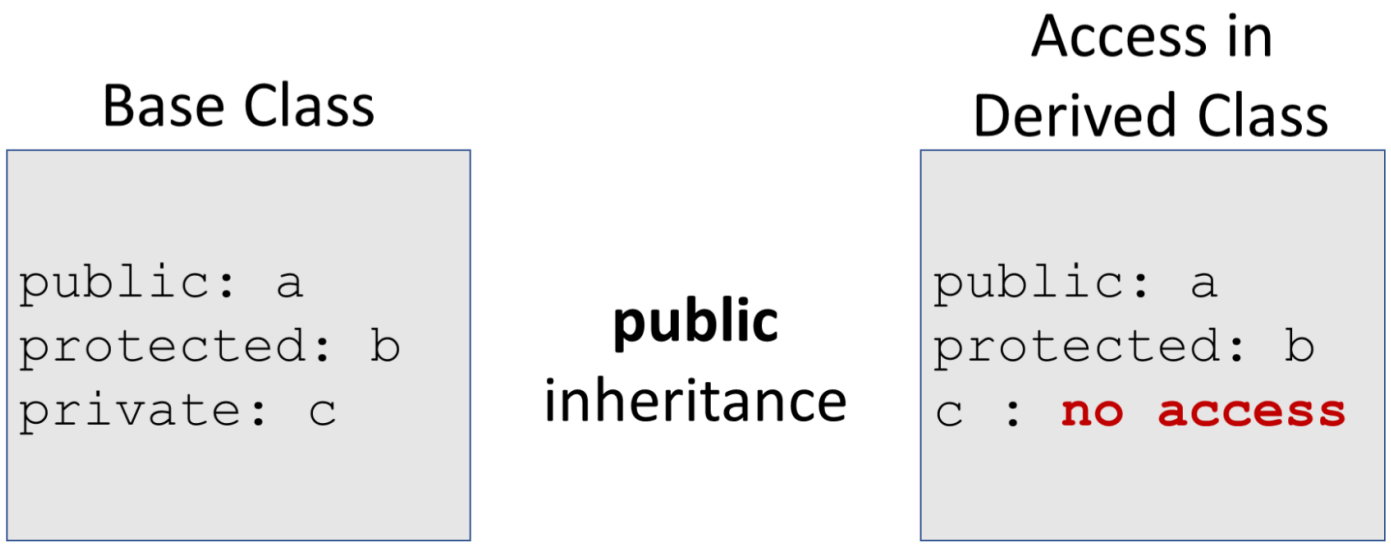
Protected Members and Class Access

The protected class member modifier

```
class Base {
   public:
     int a;   // public Base class members . . .


   protected:
     int b; // protected Base class members . . .


   private:
     int c; // private Base class members . . .

};
```

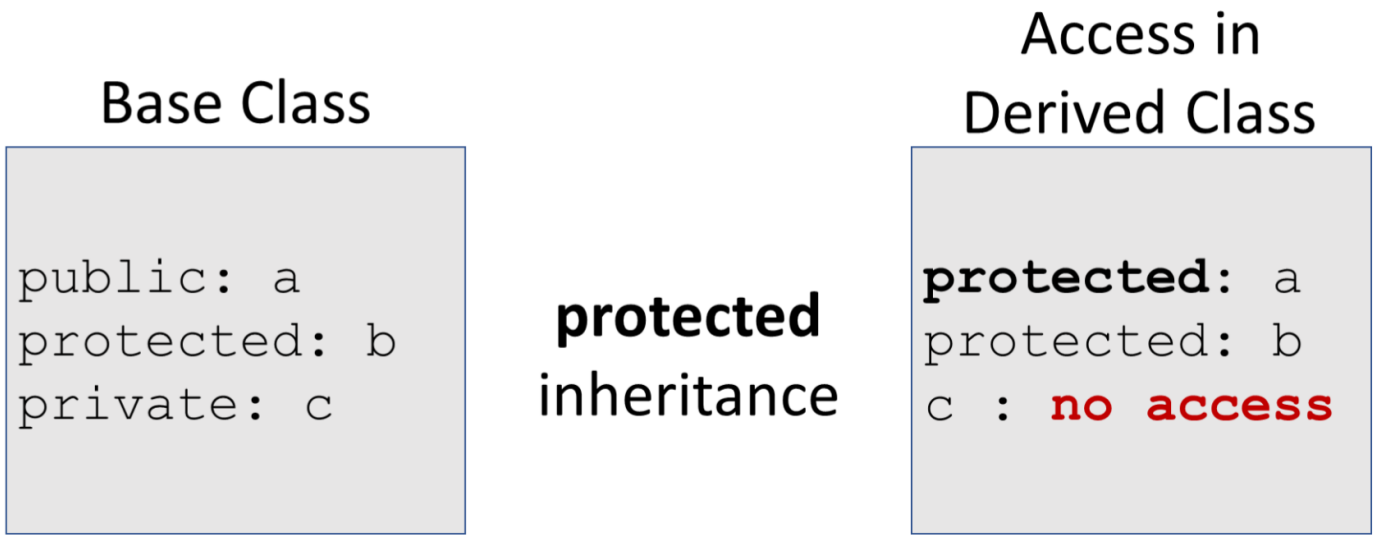
Deriving classes from exiting classes

Access with **`public`** inheritance



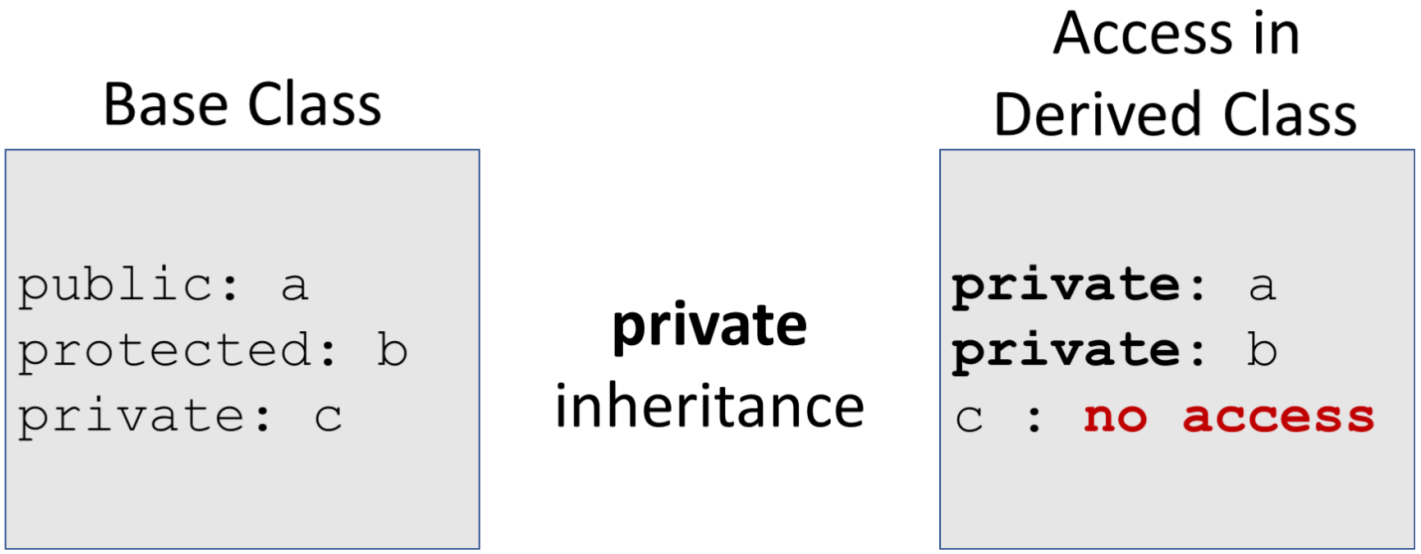
Deriving classes from exiting classes

Access with **`protected`** inheritance



Deriving classes from exiting classes

Access with **`private`** inheritance



Constructors and Destructors

Constructors and class initialization

- A Derived class inherits from its Base class
- The Base part of the Derived class MUST be initialized BEFORE the Derived class is initialized
- When a Derived object is created
  - Base class constructor executes then
  - Derived class constructor executes

Constructors and Destructors

Constructors and class initialization

```
class Base {
public:
   Base(){ cout << "Base constructor" << endl; }
};

class Derived : public Base {
public:
   Derived(){ cout << "Derived constructor " << endl; }
};
```

Constructors and Destructors

Constructors and class initialization

	Output
`Base base;`	`Base constructor`
`Derived derived;`	`Base constructor` `Derived constructor`

Constructors and Destructors

Destructors

- Class destructors are invoked in the reverse order as constructors
- The Derived part of the Derived class MUST be destroyed BEFORE the Base class destructor is invoked
- When a Derived object is destroyed
  - Derived class destructor executes then
  - Base class destructor executes
  - Each destructor should free resources allocated in it's own constructors

Constructors and Destructors

Destructors

```
class Base {
public:
   Base(){ cout << "Base constructor" << endl; }
   ~Base(){ cout << "Base destructor" << endl; }
};

class Derived : public Base {
public:
   Derived(){ cout << "Derived constructor " << endl; }
   ~Derived(){ cout << "Derived destructor " << endl; }
};
```

Constructors and Destructors

Destructors and class initialization

	Output
`Base base;`	`Base constructor` `Base destructor`

`Derived derived;`	`Base constructor`
	`Derived constructor`
	`Derived destructor`
	`Base destructor`

Constructors and Destructors

Constructors and class initialization

- A Derived class does NOT inherit
  - Base class constructors
  - Base class destructor
  - Base class overloaded assignment operators
  - Base class friend functions

- However, the derived class constructors, destructors, and overloaded assignment operators can invoke the base-class versions

- C++11 allows explicit inheritance of base 'non-special' constructors with
  - `using Base::Base;` anywhere in the derived class declaration
  - Lots of rules involved, often better to define constructors yourself

Inheritance

Passing arguments to base class constructors

- The Base part of a Derived class must be initialized first
- How can we control exactly which Base class constructor is used during initialization?
- We can invoke the whichever Base class constructor we wish in the initialization list of the Derived class

Inheritance

Passing arguments to base class constructors

```
class Base {
public:
    Base();
    Base(int);
    . . .
};

Derived::Derived(int x)
    : Base(x), {optional initializers for Derived} {
  // code
}
```

Constructors and Destructors

Constructors and class initialization

```
class Base {
    int value;
public:
    Base(): value{0} {
        cout << "Base no-args constructor" << endl;
    }
    Base(int x) : value{x} {
        cout << "int Base constructor" << endl;
    }
};
```

Constructors and Destructors

Constructors and class initialization

```
class Derived : public Base {
    int doubled_value;
public:
    Derived(): Base{}, doubled_value{0} {
        cout << "Derived no-args constructor " << endl;
    }
    Derived(int x) : Base{x}, doubled_value {x*2} {
        cout << "int Derived constructor " << endl;
    }
};
```

Constructors and Destructors

Constructors and class initialization

```
Base base;
```

Output
```
Base no-args constructor
```

```
Base base{100};
```

```
int Base constructor
```

```
Derived derived;
```

```
Base no-args constructor
Derived no-args constructor
```

```
Derived derived{100};
```

```
int Base constructor
int Derived constructor
```

Inheritance

Copy/Move constructors and overloaded operator=

- Not inherited from the Base class
- You may not need to provide your own
  - Compiler-provided versions may be just fine
- We can explicitly invoke the Base class versions from the Derived class

Inheritance

Copy constructor

- Can invoke Base copy constructor explicitly
  - Derived object '*other*' will be **sliced**

```
Derived::Derived(const Derived &other)
    : Base(other), {Derived initialization list}
{
    // code
}
```

Constructors and Destructors

Copy Constructors

```
class Base {
    int value;
public:
    // Same constructors as previous example

    Base(const Base &other) :value{other.value} {
  cout << "Base copy constructor" << endl;
    }
};
```

Constructors and Destructors

Copy Constructors

```
class Derived : public Base {
    int doubled_value;
public:
    // Same constructors as previous example

    Derived(const Derived &other)
  : Base(other), doubled_value {other.doubled_value } {
          cout << "Derived copy constructor " << endl;
    }
};
```

Constructors and Destructors

operator=

```
class Base {
   int value;
public:
   // Same constructors as previous example
   Base &operator=(const Base &rhs) {
      if (this != &rhs) {
         value = rhs.value; // assign
      }
      return *this;
   }
};
```

Constructors and Destructors

operator=

```
class Derived : public Base {
   int doubled_value;
public:
   // Same constructors as previous example
   Derived &operator=(const Derived &rhs) {
      if (this != &rhs) {
         Base::operator=(rhs);     // Assign Base part
         doubled_value = rhs.doubled_value; // Assign Derived part
      }
      return *this;
   }
};
```

Inheritance

Copy/Move constructors and overloaded operator=

- Often you do not need to provide your own

- If you **DO NOT** not define them in Derived
  - then the compiler will create them and automatically and call the base class's version

- If you **DO** provide Derived versions
  - then **YOU** must invoke the Base versions **explicitly** yourself

- Be careful with raw pointers
  - Especially if Base and Derived each have raw pointers
  - Provide them with deep copy semantics

Inheritance

Using and redefining Base class methods

- Derived class can directly invoke Base class methods
- Derived class can **override** or **redefine** Base class methods
- Very powerful in the context of polymorphism (next section)

Inheritance

Using and redefining Base class methods

```
class Account {
public:
   void deposit(double amount) { balance += amount; }
};

class Savings_Account: public Account {
public:
   void deposit(double amount) { // Redefine Base class method
      amount += some_interest;
      Account::deposit(amount);  // invoke call Base class method
   }
};
```

Inheritance

Static binding of method calls

- Binding of which method to use is done at compile time
  - Default binding for C++ is static
  - Derived class objects will use Derived::deposit
  - But, we can explicitly invoke Base::deposit from Derived::deposit
  - OK, but limited – much more powerful approach is dynamic binding which we will see in the next section

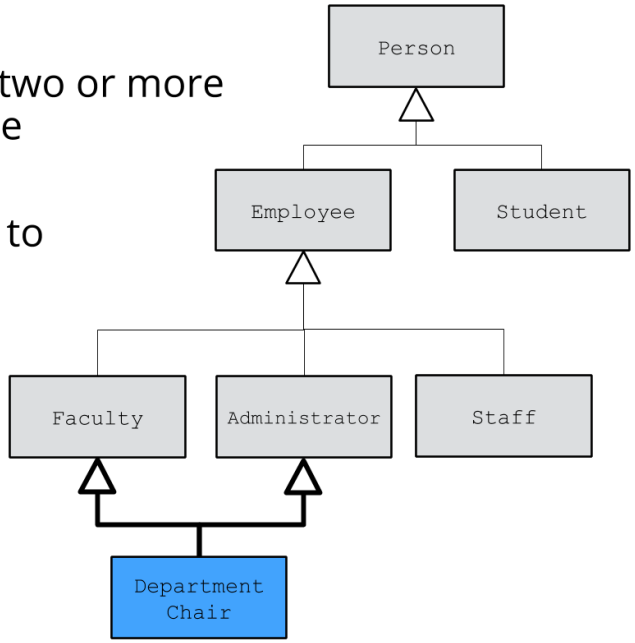
Inheritance

Static binding of method calls

```
Base b;
b.deposit(1000.0);        // Base::deposit


Derived d;
d.deposit(1000.0);        // Derived::deposit


Base *ptr = new Derived();
ptr->deposit(1000.0);      // Base::deposit ????
```

Multiple Inheritance

- A derived class inherits from two or more Base classes at the same time
- The Base classes may belong to unrelated class hierarchies
- A Department Chair
  - Is-A Faculty and
  - Is-A Administrator



Multiple Inheritance

C++ Syntax

```
class Department_Chair:
    public Faculty, public Administrator {
  . . .
};
```

- Beyond the scope of this course
- Some compelling use-cases
- Easily misused
- Can be very complex