C++ - Object Oriented Paradigm

December 4, 2017

Outline

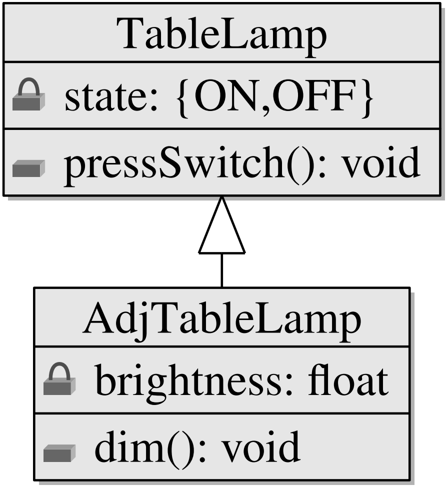
Inheritance in C++ and the Object Oriented Paradigm

Derived Classes

- covered in previous lectures: classes and objects (instances of classes)
- a derived class is defined by adding/modifying features to/of an existing class without reprogramming (no removing of features possible)
- derived classes inherit characteristics of their base classes and code is reused
- this results in a common interface for several related, but not identical classes

objects of these classes may behave differently but may be manipulated identically by other parts of the program

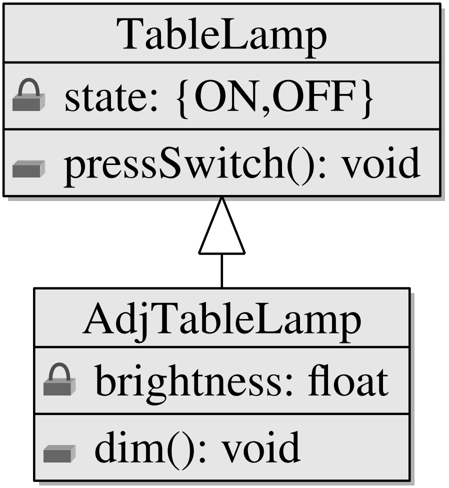
Example: Table Lamp, Adjustable Table Lamp



A table lamp may be switched on or off by pressing a switch.

An adjustable table lamp inherits all properties of a table lamp; in addition it can be dimmed.

Terminology



base class / superclass / parent class

derives / inherits from

derived class / subclass / child class

Code Example

```cpp
class TableLamp {
  enum {ON, OFF} state;
public:
  TableLamp() { state = ON; }
  void pressSwitch() {
    state = ( state == ON ? OFF : ON );
    // dim();          illegal!
    // brightness = 0.4;    illegal!
  }
  friend ostream& operator<<(ostream& o,
    const TableLamp& t) {
      return o << (t.state == TableLamp::ON ?
                   " is on" : " is off" );
  }
};
```

```
class AdjTableLamp : public TableLamp {
  float brightness;
public:
  AdjTableLamp() { brightness = 1.0; }
  void dim() {
    if (brightness > 0.1) brightness -= 0.1;
  }
  void print(ostream& o) const {
    o << *this << " with brightness "
      << brightness << endl;
  }
};
```

```
AdjTableLamp myLamp;

cout << "myLamp";
myLamp.print(cout);
  // OUT: myLamp is on with brightness 1.0

myLamp.dim();
cout << "myLamp";
myLamp.print(cout);
  // OUT: myLamp is on with brightness 0.9

myLamp.pressSwitch();
cout << "myLamp" << myLamp;
  // OUT: myLamp is off

TableLamp yourLamp;
// yourLamp.dim();          illegal!
// yourLamp.print(cout);    illegal!
```

```
AdjTableLamp* hisLamp = new AdjTableLamp();

cout << "hisLamp"; hisLamp->print(cout);
  // OUT: hisLamp is on with brightness 1.0

hisLamp->dim();
cout << "hisLamp";
hisLamp->print(cout);
  // OUT: hisLamp is on with brightness 0.9

hisLamp->pressSwitch();
cout << "hisLamp" << *hisLamp;
  // OUT: hisLamp is off

TableLamp* herLamp = new TableLamp();
// herLamp->dim();         illegal!
// herLamp->print(cout);    illegal!
```

- objects of a derived class inherit all the members of the base class
  e.g. `myLamp.pressSwitch()`, `hisLamp->pressSwitch()`
- but objects of the base class do not have access to the features of the derived class
- objects of a derived class may have additional features
  e.g. `myLamp.dim()`, `hisLamp->print(cout)`
  modification of existing features (overriding, redefining) will be discussed shortly
- objects of a derived class may be used where an object of a base class is expected (common interface)
  e.g. `cout << myLamp`, `cout << *hisLamp`

Implicit conversion of pointers

```
AdjTableLamp* hisLamp = new AdjTableLamp();

TableLamp* herLamp = hisLamp; // OK
// hisLamp = herLamp;          illegal!

AdjTableLamp myLamp;
TableLamp theirLamp;

herLamp = &myLamp                // OK
// hisLamp = &theirLamp;           illegal!

/* If we allowed the illegal assignments above
   what would happen if we then did:

    hisLamp->dim()
    hisLamp->print(cout)                    */
```

Implicit conversion of pointers

- pointers to a derived class may be implicitly converted to pointers to a base class
  e.g. `herLamp = hisLamp`, `herLamp = &myLamp`
- but not vice-versa

Assignment and Inheritance: Objects

```
AdjTableLamp myLamp; TableLamp yourLamp;

myLamp.pressSwitch();
cout << "myLamp "; myLamp.print(cout);
  // OUT: myLamp is off with brightness 1.0
cout << "yourLamp" << yourLamp;
  // OUT: yourLamp is on

yourLamp = myLamp;

cout << "yourLamp" << yourLamp;
  // OUT: yourLamp is off

myLamp.pressSwitch();
cout << "myLamp" << myLamp;
  // OUT: myLamp is on
cout << "yourLamp" << yourLamp;
  // OUT: yourLamp is off
```

Assignment and Inheritance: Pointers

```
AdjTableLamp* hisLamp = new AdjTableLamp();
TableLamp* herLamp;

herLamp = hisLamp;

cout << "herLamp" << *herLamp;
  // OUT: herLamp is on
cout << "hisLamp"; hisLamp->print(cout);
  // OUT: hisLamp is on with brightness 1.0

hisLamp->pressSwitch();

cout << "hisLamp"; hisLamp->print(cout);
  // OUT: hisLamp is off with brightness 1.0
cout << "herLamp" << *herLamp;
  // OUT: herLamp is off

delete hisLamp;   // what's wrong with this?
// delete herLamp        very bad!
```

- assignment to objects of derived class to objects of base class
  `yourLamp = myLamp`

  copies all data members defined in the base class (`TableLamp`) from `myLamp` to `yourLamp` and does not change the class of the object assigned to (`yourLamp`)
- assignment of pointers
  `herLamp = hisLamp`

  makes herLamp and hisLamp point to the same object, but still only features of TableLamp can be accessed on herLamp

Assignment and Inheritance: References

```
AdjTableLamp myLamp; TableLamp yourLamp;

AdjTableLamp& myLampRef = myLamp;
TableLamp& yourLampRef = yourLamp;

myLampRef.pressSwitch()
cout << "myLampRef"; myLampRef.print(cout);
  // OUT: myLampRef is off with brightness 1.0
cout << "yourLampRef" << yourLampRef;
  // OUT: yourLampRef is on
yourLampRef = myLampRef;
cout << "yourLampRef" << yourLampRef;
  // OUT: yourLampRef is off

myLampRef.pressSwitch();
cout << "myLampRef"; myLampRef.print(cout);
  // OUT: is on with brightness 1.0
cout << "yourLampRef" << yourLampRef;
  // OUT: yourLampRef is off
```

Assignment and Inheritance: References Cont.

```
AdjTableLamp myLamp, myOtherLamp;

AdjTableLamp& myLampRef = myLamp;
TableLamp& myOtherLampRef = myOtherLamp;

myLampRef.dim(); myLampRef.pressSwitch();
cout << "myLampRef"; myLampRef.print(cout);
  // OUT: myLampRef is off with brightness 0.9
cout << "myOtherLampRef" << myOtherLampRef;
  // OUT: myOtherLampRef is on

myOtherLampRef = myLampRef;

cout << "myOtherLampRef" << myOtherLampRef;
  // OUT: myOtherLampRef is off
cout << "myOtherLamp"; myOtherLamp.print(cout);
  // OUT: myOtherLamp is off with brightness 1.0
```

Assignment and Inheritance
References

- assignment of references
  `yourLampRef = myLampRef`

  behaves like assignment of objects, i.e. it copies all data members defined in `TableLamp` from `myLampRef` to `yourLampRef` and does not change the class of the object aliased by `yourLampRef`
- if a `TableLamp` reference actually aliases an `AdjTableLamp` object,
  `myOtherLampRef = myLampRef`

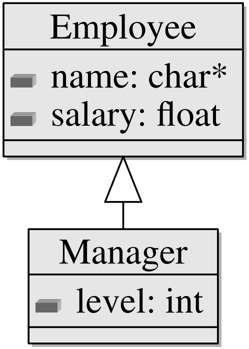
  then assignment of references *still* behaves like assignment of objects, i.e. the `AdjTableLamp` attributes are *not* copied.

```
// But don't forget references are aliases
AdjTableLamp myLamp;

AdjTableLamp& myLampRef = myLamp;
TableLamp& yourLampRef = myLamp;

cout << "myLampRef"; myLampRef.print(cout);
  // OUT: myLampRef is on with brightness 1.0

yourLampRef.pressSwitch();
cout << "yourLampRef" << yourLampRef;
  // OUT: yourLampRef is off

cout << "myLampRef"; myLampRef.print(cout);
  // OUT: myLampRef is off with brightness 1.0
```

```
class TableLamp {
  ...
  friend ostream& operator<<(ostream& o,
                              TableLamp& t) {
      // If TableLamp& t not const
    ...
  }
};

class AdjTableLamp : public TableLamp {
  ...
  void print(ostream& o) const {
    o << *this  ...
    // compile error: no match for operator<<
  }
};
```

Constructors and Inheritance
Base Class Initializers

- the base class constructor must be called through a base class initializer
- if the base class constructor has arguments, then these arguments must be provided in the base class initializer



Employees have a name, and earn a salary.

Managers are employees; thus they inherit all employee properties. They are paid according to their level.

```cpp
class Employee {

protected:
  char* name;
  float salary;

public:
  Employee(float s, char* n) {
    salary = s;
    name = n;
  }

  friend ostream& operator<< (ostream& o,
    const Employee& e) {
      return o << e.name << " earns " << e.salary;
  }

};
```

```
class Manager : public Employee {

private:
  int level;

public:
  Manager(int l, char* n) : Employee(10000.0 * l, n) {
    level = l;
  }

  ostream& operator>>(ostream& o) const {
    return o << *this << " at level " << level;
  }
};
```

```
int main() {

Manager Scrooge(5, "Scrooge MacDuck");
Employee Donald(13456.5, "Donald Duck");

cout << Donald << endl;
  // OUT: Donald Duck earns 13456.5

cout << Scrooge << endl;
  // OUT: Scrooge MacDuck earns 50000.0

Scrooge >> cout << endl;
  // OUT: Scrooge MacDuck earns 50000.0 at level 5

return 0;
}
```

Base class initializers are implicitly introduced by the compiler; this is why the following produces a compile time error:

```
class WrongManager : public Employee {
  private:
    int level;
  public:
    WrongManager(int l, char* n) {
      level = l; name = n;
      salary = 10000.0 * l;
    }
//  Error: no matching function call to
       'Employee::Employee()'
};
```

Question: Why was there no corresponding error in the constructor for `AdjTableLamp`?

Constructors, Destructors and Inheritance

- Objects are constructed from top to bottom: first the base class and then the derived class (first members then constructor)
- They are destroyed in the opposite order: first the derived class and then the base class (first destructor then members)

Example:

Employees are given a desk, and share offices. Bosses are employees, but they are also given PCs. On their first day at work, Bosses turn their PCs on; when they are fired they switch their PC off.

```cpp
class Desk {
public:
  Desk() { cout << "Desk::Desk() \n"; }
  ~Desk() { cout << "Desk::~Desk() \n"; }
};

class Office {
public:
  Office() { cout << "Office::Office() \n"; }
  ~Office() { cout << "Office::~Office() \n"; }
};

class PC {
public:
  PC() { cout << "PC::PC() \n"; }
  ~PC() { cout << "PC::~PC() \n"; }

  void turnOn() { cout << "turns PC on \n"; }
  void turnOff() { cout << "turns PC off \n"; }
};
```

```
class Empl {
  Desk myDesk;
  Office* myOffice;
public:
  Empl(Office* o) {
    myOffice = o;
    cout << "Empl::Empl() \n";
  }
  ~Empl() { cout << "Empl::~Empl() \n"; }
};
class Boss : public Empl {
  PC myPC;
public:
  Boss(Office* o) : Empl(o) {
    myPC.turnOn(); cout << "Boss::Boss() \n";
  }
  ~Boss() {
    myPC.turnOff(); cout << "Boss::~Boss() \n";
  }
};
```

```
int main() {

Office* pOff;
pOff = new Office();
  // OUT: Office::Office()

Empl* pEmpl = new Empl(pOff);

  /* OUT: Desk::Desk()
        Empl::Empl() */

delete pEmpl;

  /* OUT: Empl::~Empl()
        Desk::~Desk() */
```

Notice

The destructor for employees does not automatically destroy the office (nor should it - why?).

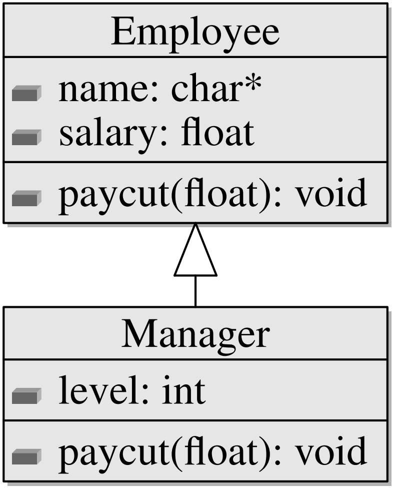
```
Boss* pBoss = new Boss(pOff);

  /* OUT: Desk::Desk()
         Empl::Empl()
         PC::PC()
         turns PC on
         Boss::Boss() */

delete pBoss;

  /* OUT: turns PC off
         Boss::~Boss()
         PC::~PC()
         Empl::~Empl()
         Desk::~Desk() */
```

Virtual Functions

So far, we only know half the truth about inheritance: its real power and usefulness lies in *virtual functions* (adding vs. modifying features)

- Method binding is the process of determining which method to execute for a given call.
- In C++ we have both static and dynamic method binding.
- When a virtual member function is called, the class of the receiver determines which function will be executed.
- The keyword `virtual` indicates that a function is virtual.

Example



Employees have a name, and earn a salary. When they receive a pay cut, their salary is reduced by the specified amount.

Managers are employees; When they receive a pay cut their salary is incremented by the specified amount multiplied by their level.

The function `paycut(float)` will be implemented as a virtual member function.

```
class Employee {

protected:
  char* name;
  float salary;

public:
  Employee(float s, char* n) { salary = s; name = n;}

  friend ostream& operator<<(ostream& o,
    const Employee& e) {
      return o << e.name << " earns " << e.salary;
  }

  virtual void paycut(float amount) {
    salary -= amount;
  }
};
```

```
class Manager : public Employee {

private:
  int level;

public:
  Manager(int l, char* n) : Employee(10000.0 * l, n){
    level = l;
  }

  friend ostream& operator<< (ostream& o,
    const Manager& m) {
      return o << (Employee) m << " at level "
            << m.level;
  }

  virtual void paycut(float amount) {
    salary += amount * level;
  }
};
```

The function

```
virtual void paycut(float amount)
```

is virtual, but the operators

```
ostream& operator<<(ostream& o, const Employee& e)

ostream& operator<<(ostream& o, const Manager& m)
```

are overloaded - not virtual.

- The construction `(Employee) m` is called a type cast. It requires the compiler to consider `m` as being of type `Employee` (also see `static_cast<>` and `dynamic_cast<>`)
- Note: downward type casts can be dangerous

```cpp
int main()
{
  Manager Scrooge(5, "SMD");
  Employee Donald(13456.5, "DD");

  cout << Donald << endl;
    // OUT:   DD earns 13456.5
  Donald.paycut(300);
  cout << Donald << endl;
    // OUT:   DD earns 13156.5
  cout << Scrooge << endl;
    // OUT:   SMD earns 50000.0 at level 5
  Scrooge.paycut(300);
  cout << Scrooge << endl;
    // OUT:   SMD earns 51500.0 at level 5
  Scrooge.Employee::paycut(300);
  cout << Scrooge << endl;
    // OUT:   SMD earns 51200.0 at level 5
  return 0;
}
```

Virtual Functions, Static and Dynamic Binding

- We distinguish between static and dynamic binding for functions.
- Static binding: function to be executed is determined at compile-time
- Dynamic binding: function to be executed can only be determined at run-time
- In C++, virtual functions are bound dynamically if the receiver is a pointer, i.e. `pointer->f(...)` is bound dynamically if `f` is virtual
- All other functions (virtual or non-virtual) are bound statically according to the class of the object executing the function
- The most powerful effect is produced by the combination of virtual functions and pointers.

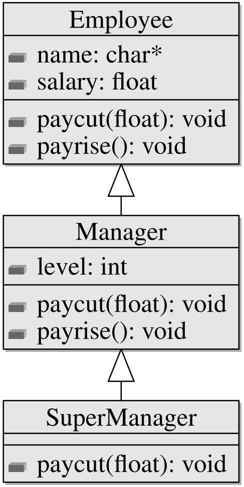
Design Philosophy

Language Design Philosophy

In other OO languages, e.g. C# or Java, there is only dynamic binding.

- Which mode is more important for OO?
- Why are there two modes of binding in C++?

Virtual Functions - Example



Employees have a name, and earn a salary. `paycut`, reduces their salary by the specified amount. `payrise` increases salary by 800.

Managers are employees; When they receive a `paycut` their salary is incremented by the specified amount multiplied by their level. A `payrise` increases salary by 100.

SuperManagers are Managers. They double their salary when they get a `paycut`.

In order to demonstrate the issues around virtual functions, we declare:

```
Employee::paycut(float) as a virtual function
Employee::payrise() as a non-virtual function
```

In addition, we say that the function

```
Manager::payrise()
```

redefines

```
Employee::payrise()
```

and

```
Manager::paycut()
```

overrides

```
Employee::paycut()
```

```
class Employee {

  ... // same as before

  friend ostream& operator<<(ostream& o,
    const Employee& e) {
      return o << e.name << " earns " << e.salary;
  }

  virtual void paycut(float amount) {
    salary -= amount;
  }

  void payrise() { salary += 800; }
};
```

```
class Manager : public Employee {

  ... // same as before

  friend ostream& operator<<(ostream& o,
    const Manager& m) {
      return o << (Employee) m << " at level "
            << m.level;
  }

  virtual void paycut(float amount) {
    salary += amount * level;
  }

  void payrise() { salary += 100; }

};
```

```cpp
class SuperManager : public Manager {

public:
  SuperManager(char* n) : Manager(10, n) {}

  virtual void paycut(float amount) {
    salary *= 2;
  }
};
```

```
int main() {

  Manager*  M1 = new Manager(5, "ScrMcDuck");
  Employee* E1 = new Employee(13456.5, "DonDuck");
  Employee* E2 = new SuperManager("WaltDisn");

  cout << "E1: " << *E1 << endl;
    // OUT:   E1: DonDuck earns 13456.5


  E1->paycut(300);
  cout << "E1: " << *E1 << endl;
    // OUT:   E1: DonDuck earns 13156.5

  E1->payrise();
  cout << "E1: " << *E1 << endl;
    // OUT:   E1: DonDuck earns 13956.5
```

```
cout << "M1: " << *M1 << endl;
  // OUT:   M1: ScrMcDuck earns 50000 at level 5

M1->paycut(300);
cout << "M1: " << *M1 << endl;
  // OUT:   M1: ScrMcDuck earns 51500 at level 5

M1->payrise();
cout << "M1: " << *M1 << endl;
  // OUT:   M1: ScrMcDuck earns 51600 at level 5

cout << "E2: " << *E2 << endl;
  // OUT:   E2: WaltDisn earns 100000
E2->paycut(300);
cout << "E2: " << *E2 << endl;
  // OUT:   E2: WaltDisn earns 200000

E2->payrise();
cout << "E2: " << *E2 << endl;
  // OUT:   E2: WaltDisn earns 200800
```

```
E2 = E1;
cout << "E2: " << *E2 << endl;
  // OUT:   E2: DonDuck earns 13956.5

E2->paycut(300);
cout << "E2: " << *E2 << endl;
  // OUT:   E2: DonDuck earns 13656.5

E2->payrise();
cout << "E2: " << *E2 << endl;
  // OUT:   E2: DonDuck earns 14456.5
```

Static Binding for Objects

```
Employee Donald(30000.0, "Donald Duck");
SuperManager Walter("Walter Disney");

cout << "Donald: " << Donald << endl;
  // OUT:   Donald: Donald Duck earns 30000

Donald.paycut(300);
cout << "Donald: " << Donald << endl;
  // OUT:   Donald: Donald Duck earns 29700

Donald.payrise();
cout << "Donald: " << Donald << endl;
  // OUT:   Donald: Donald Duck earns 30500
```

Static Binding for Objects Cont.

```
    cout << "Walter: " << Walter << endl;
      // OUT:   Walter: Walter Disney earns 100000 at
      //              level 10

    Donald = Walter;
    // Object assignment (copying of fields)

    cout << "Donald: " << Donald << endl;
      // OUT:   Donald: Walter Disney earns 100000

    Donald.paycut(300);
    cout << "Donald: " << Donald << endl;
      // OUT:   Donald: Walter Disney earns 99700

    Donald.payrise();
    cout << "Donald: " << Donald << endl;
      // OUT:   Donald: Walter Disney earns 100500

    return 0;
}
```

Example of dynamic binding

- `E2->paycut(300)` which results in calling
- `Employee::paycut(float)` if E2 points to an object of class `Employee`
- `Manager::paycut(float)` if E2 points to an object of class `Manager`
- `SuperManager::paycut(float)` if E2 points to an object of class `SuperManager`
- `paycut(float)` is a virtual function

Examples of static binding

- `cout << *E2` which always results in calling the `ostream& operator<<(ostream&, Employee&)` function even if `E2` points to an object of class `Manager` or class `SuperManager`
- `E2->payrise()`, which always results in calling `Employee::payrise()` even if `E2` points to an object of class `Manager` or class `SuperManager`.
- `Donald.paycut(300)`, which always results in calling `Employee::paycut(float)` even after the assignment `Donald = Walter`

Summary - Virtual Functions

- the class of the object executing the member function determines which function will be executed
  - for objects, the class of the object is known at compile time, therefore static binding
  - for pointers (and references), the class of object is unknown at compile time, therefore dynamic binding (but only if the function is virtual).
- The difference between virtual functions (overriding) and non-virtual (redefining) functions, e.g. `Employee::paycut(int)` vs `Employee::payrise()`, is subtle
- in general: if a function should behave differently in subclasses, then it should be declared virtual

Language Design Philosophy

- static binding results in faster programs; dynamic binding allows for flexibility at run-time
- programmers should use dynamic binding only when necessary
- C++ aims for:
  - as much static binding as possible (i.e. for non-virtual functions, for non-pointer receivers)
  - dynamic binding only when necessary (i.e. only for calls of virtual function if the receiver is a pointer)

The type system (compiler) guarantees that when you access a member variable or member function, then the receiver will always have such a member, i.e. invoking methods and accessing fields always leads to well-defined behaviour.

What makes a function virtual?

- virtual functions are preceded by the keyword `virtual`
- a function with same identifier and arguments in a subclass is virtual as well (also see `override` specifier sice C++11)

```
class Food {
public:
  virtual void print() { cout << " food \n"; }
};

class FastFood: public Food {
public:
  void print() { cout << " fast food \n"; }
};

class Pizza: public FastFood {
public:
  void print() { cout << " salami, pepperoni \n"; }
};
```

The functions Food::print(), FastFood::print() and Pizza::print() are all virtual, even though only the function Food::print() contains the keyword virtual in its declaration.

In other words, the keyword virtual in the declaration of the overriding functions can be omitted.

```
int main() {
  Food* f; f = new Food; f->print();
    // OUT: food
  f = new FastFood; f->print();
    // OUT: fast food
  f = new Pizza; f->print();
    // OUT: salami, pepperoni
  FastFood* ff; ff = new FastFood; ff->print();
    // OUT: fast food
  ff = new Pizza; ff->print();
    // OUT: salami, pepperoni
}
```

Binding for Local Function Calls

- for a member function `f`, inside code of the containing class, the function call `f(...)` corresponds to `this->f`
- thus local function calls can be bound dynamically

Example

```
class Human {
  public:
  void holiday() {
    cout << "spends holidays ";
    enjoying();
}

  virtual void enjoying() {
    cout << " relaxing\n";
  }
};
```

```cpp
class Italian: public Human {
public:
  void enjoying() override {
    cout << " on the beach\n";
  }
};
class Swede: public Human {
public:
  void enjoying() override {
    cout << " in the sauna\n";
  }
};
int main() {
  Italian Giuseppe; Swede Stefan;
  cout << "Giuseppe "; Giuseppe.holiday();
    // OUT:  Giuseppe spends holidays on the beach
  cout << "Stefan "; Stefan.holiday();
    // OUT:  Stefan spends holidays in the sauna
}
```

This example demonstrates the Template Method Design Pattern

When the behaviour of objects of different classes bears some similarities, but differences in some aspects, then one should extract the common behaviour into a member function of a superclass, and express the differing aspects through the call of virtual functions.

Such an approach:

- supports reuse of code
- more maintainable
- clarifies similarities, stresses differences

Virtual Destructors

- Destructors are bound according to the same rules as any other member function - in particular, they can be `virtual`.
- There are no virtual constructors. Cloning operators and factory design patterns play this role.

```cpp
class Empl {
public:
  ~Empl() { cout << "Empl::~Empl() \n"; }
};

class Boss : public Empl {
public:
  ~Boss() { cout << "Boss::~Boss() \n"; }
};

class EmplV {
public:
  virtual ~EmplV() { cout << "EmplV::~EmplV() \n"; }
};

class BossV : public EmplV {
public:
  ~BossV() { cout << "BossV::~BossV() \n"; }
};
```

```
int main() {

  Empl* pEmpl = new Boss();
  delete pEmpl;
    // OUT: Empl::~Empl()

  EmplV* pEmplV = new BossV();
  delete pEmplV;
    /* OUT: BossV::~BossV()
            EmplV::~EmplV() */

  return 0;
}
```

- it is a good policy to always make destructors virtual
- also solves the issue of undefined behaviour if deleting objects of subclasses through base class pointers (see TableLamp example)

Overloading and Overriding

- Overloading:
  - if several function declarations share the same name
  - appropriate function body is selected by comparing the types of actual arguments with the types of formal parameters (function signature)
  - inheritance is not required for overloading to occur
- Overriding: a virtual function `f` defined in a derived class `D` overrides a virtual function `f` defined in a base class `B`, if the two functions share the same parameter types. (`D::f` is allowed to return a subtype of the return type of `B::f`.) Calling `f` on an object of class `D` invokes `D::f`.

Overloading

Types are known at compile time, therefore:

- Overloading is resolved statically according to the compile time type of the arguments.

Example of overloading:

Humans chat with one another; when one human meets another, then they (invariably) talk about the weather. If a person meets someone that they know is a computer scientist, then they talk about how computer illiterate they are.

```cpp
class Human {
public:
  void chatsWith(Human h) {
    cout << "about the weather";
  }

  void chatsWith(ComputerScientist c) {
    cout << "about their computer illiteracy";
  }

};

class ComputerScientist : public Human {};
```

```cpp
int main() {
  Human* someone;
  Human* someone_else;
  Human john;
  ComputerScientist julia;

  someone = new Human;

  john.chatsWith(*someone);
    // OUT: about the weather
  john.chatsWith(julia);
    // OUT: about their computer illiteracy

  someone = &julia;
  john.chatsWith(*someone);
    // OUT: about the weather
  someone_else->chatsWith(john);
     // OUT: about the weather
  // why does an uninitialized pointer
  // not cause errors?
}
```

Overriding

Classes are known only at run time, therefore:

- Overriding is resolved according to the run time class of the receiver, if possible statically, otherwise dynamically.
- Notice that functions may be involved in both overloading and overriding.

Example of overriding:

When a computer scientist meets someone else, they talk about computer games; when they meet another computer scientist, then they chat about other people's computer illiteracy!

```
class Human {
public:
  virtual void chatsWith(Human* h) {
    cout << "about the weather";
  }
  virtual void chatsWith(ComputerScientist* c) {
    cout << "about their own computer illiteracy";
  }
};
class ComputerScientist : public Human {
public:

  virtual void chatsWith(Human* h) {
    cout << " about computer games";
  }

  virtual void chatsWith(ComputerScientist* c) {
    cout << " about others' computer illiteracy";
  }
};
```

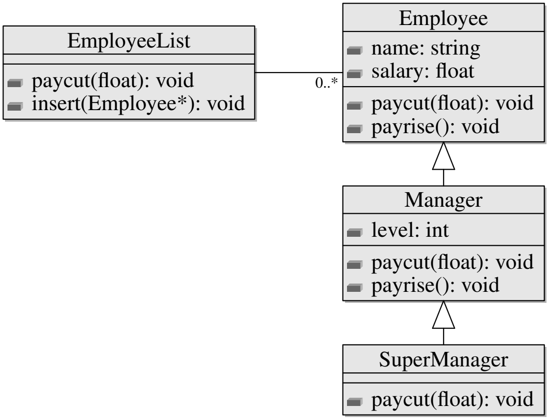
```cpp
int main() {

  Human John, *Paul;
  ComputerScientist Julia, *Paola;

  John.chatsWith(Paul);
    // OUT: about the weather

  John.chatsWith(Paola);
    // OUT: about their own computer illiteracy

  Julia.chatsWith(Paul);
    // OUT: about computer games

  Julia.chatsWith(Paola);
    // OUT: about others' computer illiteracy
    Human* Han = new Human;

    Han->chatsWith(Paul);
      // OUT: about the weather

    Han->chatsWith(Paola);
      // OUT: about their own computer illiteracy

    Han = new ComputerScientist;

    Han->chatsWith(Paul);
      // OUT: about computer games

    Han->chatsWith(Paola);
      // OUT: about others' computer illiteracy

    Paul->chatsWith(Han);
    //  Segmentation fault!     Why?
}
```

Example Summary

- `Human::chatsWith(Human*)` overloads `Human::chatsWith(ComputerScientist*)`
- `ComputerScientist::chatsWith(Human*)` overloads `ComputerScientist::chatsWith(ComputerScientist*)`
- `ComputerScientist::chatsWith(Human*)` overrides `Human::chatsWith(Human*)`
- `ComputerScientist::chatsWith(ComputerScientist*)` overrides `Human::chatsWith(ComputerScientist*)`

Polymorphism and Dynamic Binding

Polymorphism allows us to uniformly define and manipulate structures consisting of objects which share some characteristics, but still differ in some details. Consider a list containing employees and/or managers and/or supermanagers:



```
// classes Employee, Manager, SuperManager as before

class EmployeeList {

  EmployeeList* next;
  Employee* theEmployee;

public:

  EmployeeList(Employee* e) : theEmployee(e),
    next(nullptr) {}

  void insert(Employee* e) {

    EmployeeList* newList = new EmployeeList(e);
    newList->next = next;
    next = newList;

  }
  friend ostream& operator<<(ostream& o,
    const EmployeeList& l){

      o << *(l.theEmployee) << endl;

      return (l.next == nullptr) ? o << endl
                                 : o << *(l.next);
  }

  void paycut(float a) {

    theEmployee->paycut(a);
    if (next != nullptr) next->paycut(a);

  }

};
```

```cpp
int main() {

  EmployeeList disneyList(
      new Manager(5, "Scrooge Mac Duck")
    );

  disneyList.insert(
      new Employee(13456.5,"Donald Duck")
    );

  disneyList.insert(
      new SuperManager("Walter Disney")
    );

  disneyList.insert(
      new Employee(45.7,"Louie Duck")
    );

    ...
```

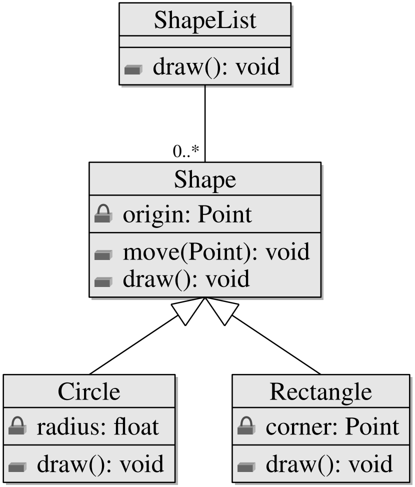
Cont.

```
    cout << disneyList;
    /* OUT: Scrooge Mac Duck earns 50000
          Louie Duck earns 45.7
          Walter Disney earns 100000
          Donald Duck earns 13456.5 */

    disneyList.paycut(40);

    cout << disneyList;
    /* OUT: Scrooge Mac Duck earns 50200
          Louie Duck earns 5.7
          Walter Disney earns 200000
          Donald Duck earns 13416.5 */

    return 0;
}
```

Each element in the list reacts differently to the paycut, according to its (dynamically determined) class.

Pure Virtual Functions, Abstract Classes

- When we only need a function to define an interface, we can leave its implementation unspecified.
  ```
  virtual void myFunction() = 0;
  ```
- This is called a `pure` virtual function.
- A class that contains at least one pure virtual function is called an abstract class.
- No objects of an abstract class may be created.
- Client code knows that all objects of derived classes provide this function.
- Classes that inherit pure virtual functions and do not override them are also abstract.



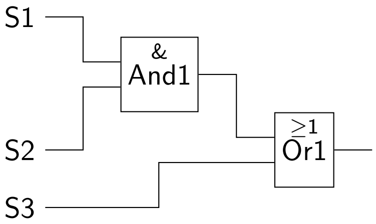
The pure virtual function `draw()` is indispensable!

```
class Shape{
  Point origin;
public:
  void move(Point p)
    { origin += p; };
  virtual void draw()=0;
}

class ShapeList{
  Shape* theShape;
  ShapeList* next:
public:
  void draw()
   { theShape->draw();
     ... next->draw(); }
};
class Circle: public Shape{
  float radius;
public:
  void draw(){   }};
```

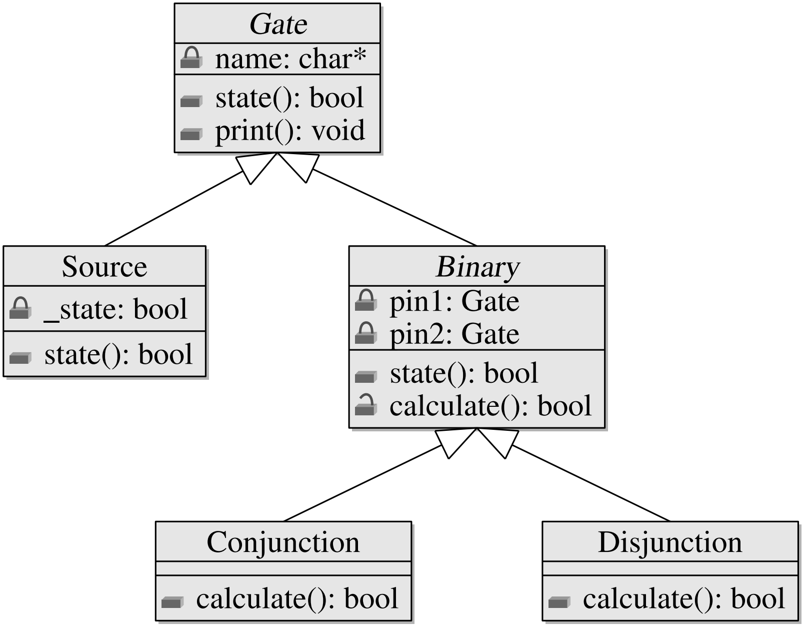
Use of Abstract Classes

- The clients of the abstract class may safely expect all the objects of subclasses of this class to implement all the public functions.
- All non-abstract subclasses of the abstract class are under the obligation to provide an implementation of the pure virtual functions
- If `ClassA` and `ClassB` are similar, but none is necessarily more general than the other, then they probably should both be subclasses of a new, common abstract superclass, `ClassC`.

Abstract Class Example: Digital Logic Gates



Abstract Class Example: Digital Logic Gates



Member Access Control

In this example, we will make use of Member Access Control.
Class members can be:

- `public` - may be used anywhere.
- `protected` - may be used by any member function of the class and by any member function of any subclass.
- `private` - may be used by member functions of the class only.

Furthermore, a friend of a class can access everything the class has access to.

```
class Gate {
  const char* name;       // private is the default
public:
  Gate(const char* name) : name(name) {}
  virtual bool state() = 0; // Pure virtual function
  virtual void print() { cout << name; }
};
```

```cpp
class Source : public Gate {

  bool _state;

public:

  Source(const char* name, bool state)
    : Gate(name), _state(state) {}

  bool state() override { return _state; }

  void print() override {
    Gate::print();
    cout << (_state ? "(1)" : "(0)");
  }

};
```

```
class Binary : public Gate {

  Gate &pin1, &pin2;

protected:
  virtual bool calculate(bool state1, bool state2)=0;

public:
  Binary(const char* name, Gate& pin1, Gate& pin2)
    : Gate(name), pin1(pin1), pin2(pin2) {}

  bool state() override {
    return calculate(pin1.state(), pin2.state());
  }

  void print() override {
    Gate::print();
    cout << "["; pin1.print();  cout << ",";
    pin2.print(); cout << "]";
  }
};
```

```
class Conjunction : public Binary {
protected:
  bool calculate(bool state1, bool state2) override {
    return state1 && state2;
  }
public:
  And(const char* name, Gate& pin1, Gate& pin2)
    : Binary(name, pin1, pin2) {}
};

class Disjunction : public Binary {
protected:
  bool calculate(bool state1, bool state2) override {
    return state1 || state2;
  }
public:
  Or(const char* name, Gate& pin1, Gate& pin2)
    : Binary(name, pin1, pin2) {}
};
```

```
int main()
{
  Gate g1("S1");
  // Compile error: cannot instantiate abstract class

  Source s1("S1", true);
  Source s2("S2", false);
  Source s3("S3", true);

  Binary* b1 = new Binary("And", s1, s2);
  // Compile error: cannot instantiate abstract class

  Binary* a1 = new Conjunction("And1", s1, s2);
  Gate* o1   = new Disjunction("Or1", *a1, s3);

  // Calling pure virtual function on abstract class
  bool state = o1->state();

    ...
```

Cont.

```
    ...

  cout << "State of ";
  o1->print();
  cout << (state ? " is 1 \n" : " is 0 \n");
  // OUT: State of Or1[And1[S1(1),S2(0)],S3(1)] is 1

  return 0;
}
```

The example above also demonstrates how superclass implementation can be called from an overriding function (`Gate::print`)

Protected Members

Member functions and friends of a class:

- can access protected members of its superclass directly
- cannot access protected non-`static` members of its superclass through a variable (obj, ptr, ref) of the superclass type

```
class Employee {
protected:
  float salary;
  static const float SALARY_STEP;
};

const float Employee::SALARY_STEP = 800.0;

class SuperManager;

class Manager : public Employee {
public:
  void blame(Employee* e);
  void thank(SuperManager* s);
  friend void punish(Manager* m);
};

class SuperManager : public Manager {};
```

```cpp
void Manager::blame(Employee* e) {
  salary += Employee::SALARY_STEP;

  e->salary -= Employee::SALARY_STEP;
  // Compile error: cannot access protected member
  // 'salary' from Employee *
}

void Manager::thank(SuperManager* s) {
  s->salary += SuperManager::SALARY_STEP;
}

void punish(Manager* m) {
  m->salary -= Employee::SALARY_STEP;
  // ((SuperManager*) m)->salary  is accessible
  //  if m is also a SuperManager
  // ((Employee*) m)->salary  is inaccessible
}
```

Access Specifiers for Base Classes

The base class of a derived class may be specified `public`, `protected` or `private`. The access specifier affects the extent to which the derived class may inherit from the superclass, and whether clients may treat objects of a subclass as if they belonged to the superclass.

```
class Goldfish : public Animal /*.... */
```

- private members of `Animal` inaccessible in `Goldfish`
- protected members of `Animal` become protected members of `Goldfish`
- public members of `Animal` become public members of `Goldfish`
- any function may implicitly transform a `Goldfish*` to an `Animal*`

Access Specifiers for Base Classes - Cont.

```
class Stack : protected List /*.... */
```

- private members of `List` inaccessible in `Stack`
- protected and public members of `List` become protected members of `Stack`
- only friends and members of `Stack` and friends and members of `Stack`'s derived classes may implicitly transform a `Stack*` to a `List*`

```
class AlarmedDoor : private Alarm /*... */
```

- private members of `Alarm` inaccessible in `AlarmedDoor`
- protected and public members of `Alarm` become private members of `AlarmedDoor`
- only friends and members of `AlarmedDoor` may implicitly transform an `AlarmedDoor*` to an `Alarm*`

The interplay of access modifiers is quite sophisticated. For our course, we concentrate on the use of access modifiers for class members, distinguish between private and public derivation, but do not worry about the distinction between private and protected derivation.

Private vs Public Derivation Example

- An `Alarm` is active or inactive, and has the ability to call the police. It is activated through the function call `set()` and deactivated through reset(). One can query its status by calling `isActive()`.
- `AlarmedDoors` have a code which controls the door: when entering the correct code one can deactivate/activate the door alarm. When one opens the door (`open()`), if the alarm is activated the police is called.
- We want to use the features of an `Alarm` to implement `AlarmedDoor` ... but is an `AlarmedDoor` a type of `Alarm`?

```cpp
class Alarm {

  bool state;

public:

  Alarm() { set(); }

  void set() { state = true; }

  void reset() { state = false; }

  bool isActive() const { return state; }

  void callPolice() {
    cout << "Police are on the way!" << endl;
  }

};
```

```cpp
class AlarmedDoor : private Alarm {
  int code;
public:
  AlarmedDoor(int code) : Alarm(), code(code) {}

  void enterCode(int codeEntered) {
    if (code == codeEntered) {
      cout << "Code correct.";
      if (isActive()) {
        reset();
        cout << "Door alarm is now deactivated."
            << endl;
      } else {
        set();
        cout << "Door alarm is now activated."
            << endl;
      }
    }
    else { cout << "Code incorrect." << endl; }
  }
```

Cont.

```
  using Alarm::isActive;

  void open() {
    if (isActive())
      callPolice();
    else
      cout << "Access granted." << endl;
  }
};

int main() {

  AlarmedDoor ad(1357);

  if (ad.isActive())
    cout << "Door alarm is active." << endl;
  // OUT: Door alarm is active.
  ad.enterCode(1357);
  // OUT: Code correct. Door alarm is now deactivated.
  ad.enterCode(2468);
  // OUT: Code incorrect.
  ad.open();
  // OUT: Access granted.
  ad.enterCode(1357);
  // OUT: Code correct. Door alarm is now activated.
  ad.open();
  // OUT: Police are on the way!

   Alarm* a = &ad;
//Compile error: Conversion to inaccessible base clas
//If we could do this, we can then do the following
//a->reset();
//ad.open();

  return 0;
}
```

So what is private inheritance for?

- Private derivation corresponds to an is-implemented-in-terms-of relationship (does not exist in the real world but implementation domain; compare to *is-a*).
- One can almost always use composition instead.
- The only benefit of private derivation is that
  - one less level of indirection (slightly less code to write)
  - you can access protected members of the base class

Language Design Philosophy - Summary

- Static binding results in faster programs.
- Dynamic binding allows for flexibility at run-time.
- Access modifiers restrict who knows what.

C++ allows you to program so that

- there is as much static binding as possible
- dynamic binding is used only when necessary
- code and objects operate on a *need to know* basis

The compiler guarantees that at run time

- objects always know how to handle method calls
- non-existent fields are not accessed
- variables contain objects of class, or subclass of their definition.

C++ Object Oriented Features - Summary

- derived classes inherit characteristics from base class
- derived class objects may be used wherever base class objects expected
- derived classes may override virtual functions
- virtual functions are bound according to class of receiver
- virtual functions are bound dynamically for pointers/references
- polymorphic structures may be programmed using pointers/references

C++ Object Oriented Features - Summary (Cont.)

- pure virtual functions declare but do not define a function
- abstract classes provide interfaces for their subclasses
- member access control supports encapsulation

C++ and Object-Oriented Good Style

- use different object types (classes) to reflect different logical entities
- let each object do the work it is responsible for
- distinguish between *is a*, *has a*, and *behaves as a*
- reuse code (via inheritance) as much as possible