

# CSCI-1200 Data Structures — Spring 2020

## Lecture 24 — C++ Inheritance and Polymorphism

### Review from Lecture 23

- What is garbage? Memory which cannot (or should not) be accessed by the program and is available for reuse.
- Explicit memory management (C++) vs. automatic garbage collection.
- Reference Counting, Stop & Copy, Mark-Sweep.
- Cyclical data structures, memory overhead, incremental vs. pause in execution, ratio of good to garbage, defragmentation.
- Smart Pointers

### Announcements

- Please fill out your course evaluations!
  - Responses to date: 133 / 462 = 28.79%
  - We know it's a weird semester, but we still appreciate the feedback
- Final exam updates:
  - Practice problems are up (Friday morning), solutions will be uploaded Tuesday evening.
  - The final will still be held Monday May 4th, but you can *start* taking it anytime during 8am - 6pm (EST). This should address most conflicts and give timezone flexibility - the latest you could submit without DSS accommodations would be 9pm EST.
  - You will have 3 hours from whenever you first open the “Final Exam” gradeable. (If you have accommodations for extra time, you can use them.)
  - There will be a text box at the bottom that lets you type in any extenuating circumstances (if you have accommodations it is a good idea to remind us just in case). We reserve the right to give a 0 to any submission that is over time.
  - If you don't like looking at screens, you can print the exam / use scratch paper, but you must submit using the “Final Exam” gradeable, meaning you will have to type your answers.
  - As before you should not use the internet (except for course materials, which we recommend you download in advance), compilers, online communication, etc. If you want to ask a family/household member to be a timekeeper for you, that's fine.
  - Your exam may look different from other student's exams.
  - Grading will be an extremely slow process due to this system and the fact that the TAs have finals too. Don't email us asking when the exam will be graded. Don't email us asking when we're releasing grades. A forum announcement will be made when final exam scores / semester grades are posted, and Rainbow Grades will be updated as well.
  - We will NOT be releasing the graded final exams electronically. The TAs and I will be working very carefully when grading the final exams since we know you would not have the opportunity to submit grade inquiries. I will be reviewing the final exams of students near semester grade borders to confirm that the grading is correct.
- Those of you interested in becoming an undergraduate mentor for Data Structures, or another CSCI course:
  - David Goldschmidt sends an email to all CSCI undergraduate majors a week or two before the start of each semester with the URL for the mentor application website. You will fill out your qualifications, weekly class schedule availability, and your course mentoring interests.
    - \* I've checked and we're still waiting on the budget, but students on the csug list will be notified when the application opens.
  - You may also speak to your graduate lab TA and ask him/her to recommend you for the position. (Though it's a little trickier this semester!)

## Today's Class

- Inheritance is a relationship among classes. Examples: bank accounts, polygons, stack & list
- Basic mechanisms of inheritance
- Types of inheritance
- Is-A, Has-A, As-A relationships among classes.
- Polymorphism

### 24.1 Motivating Example: Bank Accounts

- Consider different types of bank accounts:
  - Savings accounts
  - Checking accounts
  - Time withdrawal accounts (like savings accounts, except that only the interest can be withdrawn)
- If you were designing C++ classes to represent each of these, what member functions might be repeated among the different classes? What member functions would be unique to a given class?
- To avoid repeating common member functions and member variables, we will create a **class hierarchy**, where the common members are placed in a **base class** and specialized members are placed in **derived classes**.

### 24.2 Accounts Hierarchy

- `Account` is the *base class* of the hierarchy.
- `SavingsAccount` is a *derived* class from `Account`. `SavingsAccount` has inherited member variables & functions and ordinarily-defined member variables & functions.
- The member variable `balance` in base class `Account` is **protected**, which means:
  - `balance` is NOT publicly accessible outside the class, but it is accessible in the derived classes.
  - if `balance` was declared as **private**, then `SavingsAccount` member functions could not access it.
- When using objects of type `SavingsAccount`, the inherited and derived members are treated exactly the same and are not distinguishable.
- `CheckingAccount` is also a derived class from base class `Account`.
- `TimeAccount` is derived from `SavingsAccount`. `SavingsAccount` is its base class and `Account` is its indirect base class.

## 24.3 Exercise: Draw the Accounts Class Hierarchy

```
#include <iostream>
// Note we've inlined all the functions (even though some are > 1 line of code)

class Account {
public:
    Account(double bal = 0.0) : balance(bal) {}
    void deposit(double amt) { balance += amt; }
    double get_balance() const { return balance; }
protected:
    double balance;    // account balance
};

class SavingsAccount : public Account {
public:
    SavingsAccount(double bal = 0.0, double pct = 5.0)
        : Account(bal), rate(pct/100.0) {}
    double compound() { // computes and deposits interest
        double interest = balance * rate;
        balance += interest;
        return interest;
    }
    double withdraw(double amt) { // if overdraft ==> return 0, else return amount
        if (amt > balance) {
            return 0.0;
        } else {
            balance -= amt;
            return amt;
        }
    }
protected:
    double rate;    // periodic interest rate
};

class CheckingAccount : public Account {
public:
    CheckingAccount(double bal = 0.0, double lim = 500.0, double chg = 0.5)
        : Account(bal), limit(lim), charge(chg) {}
    double cash_check(double amt) {
        assert (amt > 0);
        if (balance < limit && (amt + charge <= balance)) {
            balance -= amt + charge;
            return amt + charge;
        } else if (balance >= limit && amt <= balance) {
            balance -= amt;
            return amt;
        } else {
            return 0.0;
        }
    }
protected:
    double limit;    // lower limit for free checking
    double charge;    // per check charge
};

class TimeAccount : public SavingsAccount {
public:
    TimeAccount(double bal = 0.0, double pct = 5.0)
        : SavingsAccount(bal, pct), funds_avail(0.0) {}
    // redefines 2 member functions from SavingsAccount
    double compound() {
        double interest = SavingsAccount::compound();
        funds_avail += interest;
        return interest;
    }
};
```

```

double withdraw(double amt) {
    if (amt <= funds_avail) {
        funds_avail -= amt;
        balance -= amt;
        return amt;
    } else {
        return 0.0;
    }
}
double get_avail() const { return funds_avail; };
protected:
    double funds_avail; // amount available for withdrawal
};

```

## 24.4 Constructors and Destructors

- Constructors of a derived class *call the base class constructor* immediately, before doing ANYTHING else. The only thing you can control is which constructor is called and what the arguments will be. Thus when a `TimeAccount` is created 3 constructors are called: the `Account` constructor, then the `SavingsAccount` constructor, and then finally the `TimeAccount` constructor.
- The reverse is true for destructors: derived class destructors do their jobs first and then base class destructors are called at the end, automatically. *Note: destructors for classes which have derived classes must be marked virtual for this chain of calls to happen.*

## 24.5 Overriding Member Functions in Derived Classes

- A derived class can redefine member functions in the base class. The function prototype must be identical, not even the use of `const` can be different (otherwise both functions will be accessible).
- For example, see `TimeAccount::compound` and `TimeAccount::withdraw`.
- Once a function is redefined it is not possible to call the base class function, unless it is explicitly called. As an example, the call to `SavingsAccount::compound` inside of `TimeAccount::compound`.

## 24.6 Public, Private and Protected Inheritance

- Notice the line `class Savings_Account : public Account {`  
This specifies that the member functions and variables from `Account` do not change their *public*, *protected* or *private* status in `SavingsAccount`. This is called *public* inheritance.
- *protected* and *private* inheritance are other options:
  - With protected inheritance, public members becomes protected and other members are unchanged
  - With private inheritance, all members become private.

## 24.7 Stack Inheriting from List

- For another example of inheritance, let's re-implement the `stack` class as a derived class of `std::list`:

```

template <class T>
class stack : private std::list<T> {
public:
    stack() {}
    stack(stack<T> const& other) : std::list<T>(other) {}
    ~stack() {}
    void push(T const& value) { this->push_back(value); }
    void pop() { this->pop_back(); }
    T const& top() const { return this->back(); }
    int size() { return std::list<T>::size(); }
    bool empty() { return std::list<T>::empty(); }
};

```

- Private inheritance hides the `std::list<T>` member functions from the outside world. However, these member functions are still available to the member functions of the `stack<T>` class.
- Note: no member variables are defined — the only member variables needed are in the list class.

- When the stack member function uses the same name as the base class (list) member function, the name of the base class followed by `::` must be provided to indicate that the base class member function is to be used.
- The copy constructor just uses the copy constructor of the base class, without any special designation because the stack object is a list object as well.

## 24.8 Is-A, Has-A, As-A Relationships Among Classes

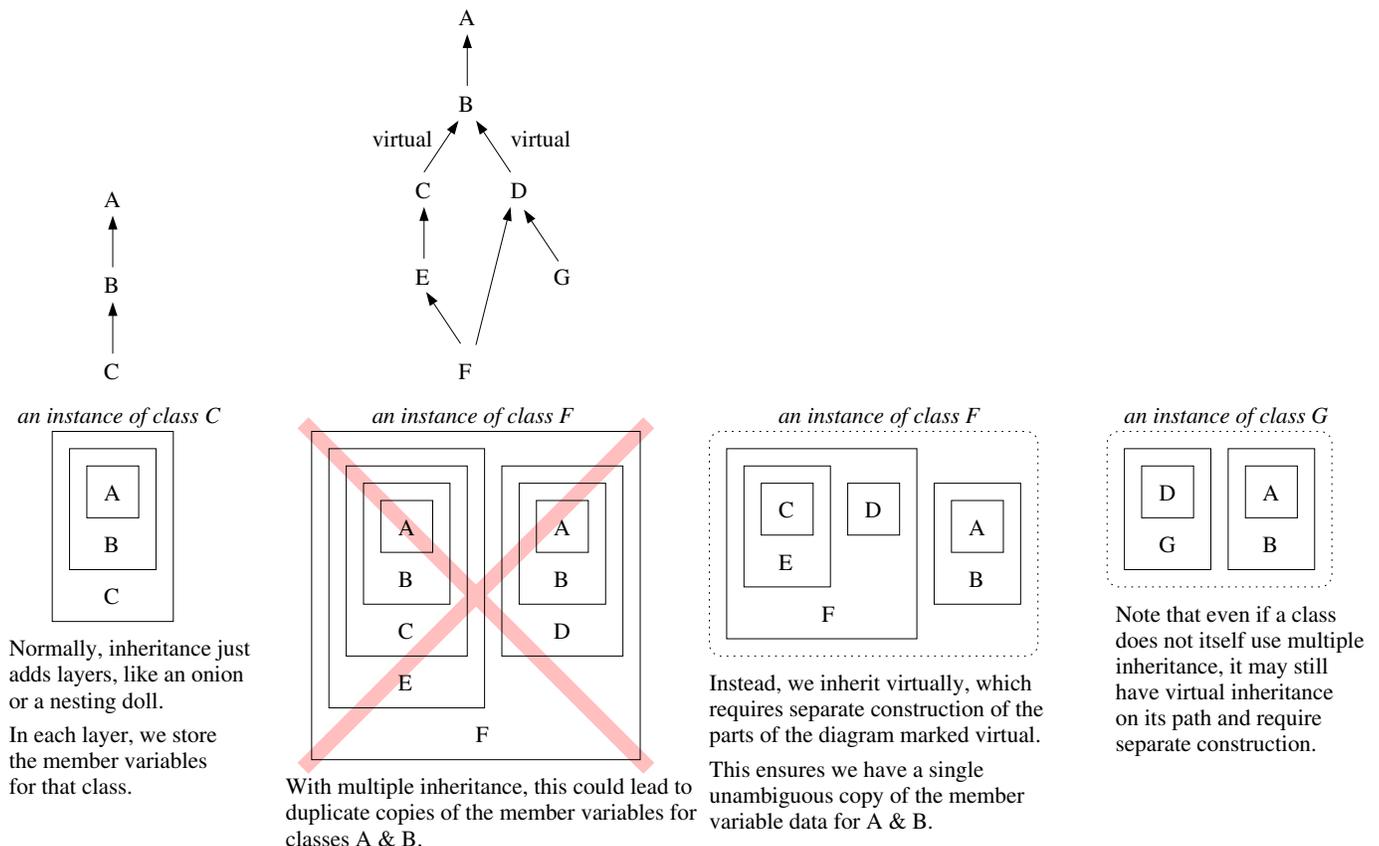
- When trying to determine the relationship between (hypothetical) classes C1 and C2, try to think of a logical relationship between them that can be written:
  - C1 is a C2,
  - C1 has a C2, or
  - C1 is implemented as a C2
- If writing “C1 is-a C2” is best, for example: “a savings account is an account”, then C1 should be a derived class (a subclass) of C2.
- If writing “C1 has-a C2” is best, for example: “a cylinder has a circle as its base”, then class C1 should have a member variable of type C2.
- In the case of “C1 is implemented as-a C2”, for example: “the stack is implemented as a list”, then C1 should be derived from C2, but with private inheritance. This is by far the least common case!

## 24.9 Exercise: 2D Geometric Primitives

Create a class hierarchy of geometric objects, such as: triangle, isosceles triangle, right triangle, quadrilateral, square, rhombus, kite, trapezoid, circle, ellipse, etc. How should this hierarchy be arranged? What member variables and member functions should be in each class?

## 24.10 Note: Multiple Inheritance

- When sketching a class hierarchy for geometric objects, your may have wanted to specify relationships that were more complex... in particular some objects may wish to inherit from *more than one base class*.
- This is called *multiple inheritance* and can make many implementation details significantly more hairy. Different programming languages offer different variations of multiple inheritance.



## 24.11 Introduction to Polymorphism

- Let's consider a small class hierarchy version of polygonal objects:

```
class Polygon {
public:
    Polygon() {}
    virtual ~Polygon() {}
    int NumVerts() { return verts.size(); }
    virtual double Area() = 0;
    virtual bool IsSquare() { return false; }
protected:
    vector<Point> verts;
};

class Triangle : public Polygon {
public:
    Triangle(Point pts[3]) {
        for (int i = 0; i < 3; i++) verts.push_back(pts[i]); }
    double Area();
};

class Quadrilateral : public Polygon {
public:
    Quadrilateral(Point pts[4]) {
        for (int i = 0; i < 4; i++) verts.push_back(pts[i]); }
    double Area();
    double LongerDiagonal();
    bool IsSquare() { return (SidesEqual() && AnglesEqual()); }
private:
    bool SidesEqual();
    bool AnglesEqual();
};
```

- Functions that are common, at least have a common interface, are in `Polygon`.
- Some of these functions are marked `virtual`, which means that when they are redefined by a derived class, this new definition will be used, even for pointers to base class objects.
- Some of these virtual functions, those whose declarations are followed by `= 0` are *pure virtual*, which means they must be redefined in a derived class.
  - Any class that has pure virtual functions is called “abstract”.
  - Objects of abstract types may not be created — only pointers to these objects may be created.
- Functions that are specific to a particular object type are declared in the derived class prototype.

## 24.12 A Polymorphic List of Polygon Objects

- Now instead of two separate lists of polygon objects, we can create one “polymorphic” list:

```
std::list<Polygon*> polygons;
```

- Objects are constructed using `new` and inserted into the list:

```
Polygon *p_ptr = new Triangle( .... );
polygons.push_back(p_ptr);
p_ptr = new Quadrilateral( ... );
polygons.push_back(p_ptr);
Triangle *t_ptr = new Triangle( .... );
polygons.push_back(t_ptr);
```

Note: We've used the same pointer variable (`p_ptr`) to point to objects of two different types.

## 24.13 Accessing Objects Through a Polymorphic List of Pointers

- Let's sum the areas of all the polygons:

```
double area = 0;
for (std::list<Polygon*>::iterator i = polygons.begin(); i!=polygons.end(); ++i)
    area += (*i)->Area();
```

Which `Area` function is called? If `*i` points to a `Triangle` object then the function defined in the `Triangle` class would be called. If `*i` points to a `Quadrilateral` object then `Quadrilateral::Area` will be called.

- Here's code to count the number of squares in the list:

```
int count = 0;
for (std::list<Polygon*>::iterator i = polygons.begin(); i!=polygons.end(); ++i)
    count += (*i)->IsSquare();
```

If `Polygon::IsSquare` had not been declared `virtual` then the function defined in `Polygon` would always be called! In general, given a pointer to type `T` we start at `T` and look “up” the hierarchy for the closest function definition (this can be done at compile time). If that function has been declared `virtual`, we will start this search instead at the actual type of the object (this requires additional work at runtime) in case it has been redefined in a derived class of type `T`.

- To use a function in `Quadrilateral` that is not declared in `Polygon`, you must “cast” the pointer. The pointer `*q` will be `NULL` if `*i` is not a `Quadrilateral` object.

```
for (std::list<Polygon*>::iterator i = polygons.begin(); i!=polygons.end(); ++i) {
    Quadrilateral *q = dynamic_cast<Quadrilateral*> (*i);
    if (q) std::cout << "diagonal: " << q->LongerDiagonal() << std::endl;
}
```

## 24.14 Exercise

What is the output of the following program?

```
class Base {
public:
    Base() {}
    virtual void A() { std::cout << "Base A "; }
    void B() { std::cout << "Base B "; }
};

class One : public Base {
public:
    One() {}
    void A() { std::cout << "One A "; }
    void B() { std::cout << "One B "; }
};

class Two : public Base {
public:
    Two() {}
    void A() { std::cout << "Two A "; }
    void B() { std::cout << "Two B "; }
};

int main() {
    Base* a[3];
    a[0] = new Base;
    a[1] = new One;
    a[2] = new Two;
    for (unsigned int i=0; i<3; ++i) {
        a[i]->A();
        a[i]->B();
    }
    std::cout << std::endl;
    return 0;
}
```