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Computer Science



CS32: Introduction to Computer Science

Discussion Week 5

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- Homework 3 is due Tuesday, February 12.
 - Check all requirements especially for recursion!
 - In Problem 2, you are required to “Replace the incorrect implementations of these functions with correct ones that use recursion in a useful way; your solution must not use the keywords `while`, `for`, or `goto`. You must not use global variables or variables declared with the keyword `static`, and you must not modify the function parameter lists.” (David Smallberg)

-
- Inheritance and polymorphism
 - Recursion (as a problem solving technique)

Inheritance & Polymorphism

From last discussion



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- **Inheritance**

- Motivation & Definition: Deriving a class from another
- Reuse, extension, specification (override)
- Construction & Destruction
- Override a member function

- **Polymorphism**

- Virtual functions
- Examples of polymorphism
- Abstract base class

Inheritance

Motivation & Review



- The basis of all *Object Oriented Programming*. And you'll almost certainly get grilled on it! --- From: Nachenberg, Slides L6P3
- The process of deriving a new class using another class as base.
- Difference of *"is a"*(class hierarchy) and *"has a"*(has member/properties)

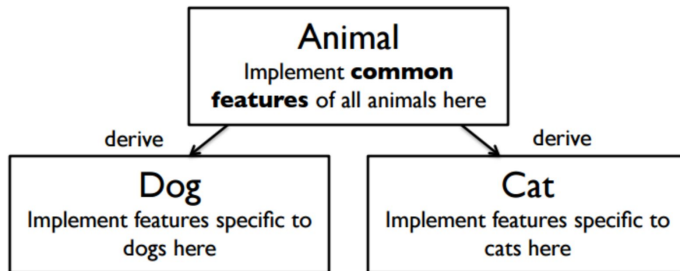
```
class Person {
public:
    string getName(void);
    void setName(string & n);
    int getAge(void);
    void setAge(int age);
private:
    string m_sName;
    int m_nAge;
};
```

```
class Student {
public:
    string getName(void);
    void setName(string & n);
    int getAge(void);
    void setAge(int age);
    int getStudentID();
    void setStudentID();
    float getGPA();
private:
    string m_sName;
    int m_nAge;
    int m_nStudentID;
    float m_GPA;
};
```

```
class Professor {
public:
    string getName(void);
    void setName(string & n);
    int getAge(void);
    void setAge(int age);
    int getProfID();
    void setProfID();
    bool getIsTenured();
private:
    string m_sName;
    int m_nAge;
    int m_nStudentID;
    bool isTenured;
};
```

Inheritance

Example: Reuse and Extension

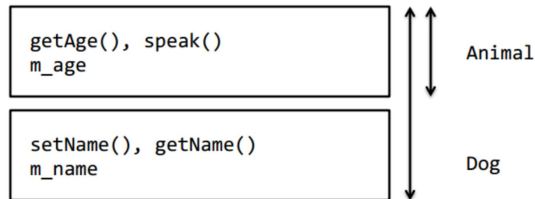


```
class Animal
{
    public:
        Animal();
        ~Animal();
        int getAge() const;
        void speak() const;
    private:
        int m_age;
};
```

base class

```
class Dog : public Animal
{
    public:
        Dog();
        ~Dog();
        string getName() const;
        void setName(string name);
    private:
        string m_name;
};
```

derived class



```
Dog d1;
d1.setName("puppy");
d1.getAge();
d1.speak();
```

```
Animal a1;
a1.speak();
a1.setName("abc");
```

- Reuse
 - Every public method in the base class is automatically reused/exposed in the derived class (just as if it were defined).
 - Only **public** members in the base class are exposed/reused in the derived class(es)! **Private** members in the base class are hidden from the derived class(es)!
 - Special case for **protected** members.
- Extension
 - All **public extensions** may be used normally by the rest of your program.
 - Extended methods or data are **unknown to your base class**.
- What about overriding a member function from base classes?

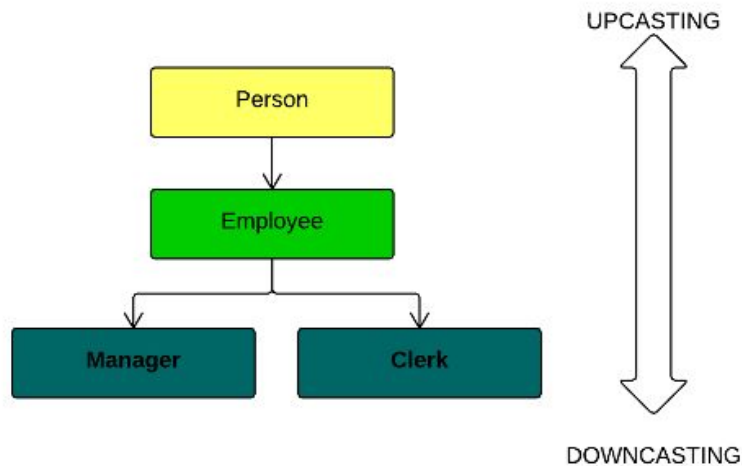
Inheritance

Automatic conversion, Upcasting, Downcasting



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- Upcasting: A derived class pointer (or reference) to be treated as base class pointer
- Downcasting: Converting base class pointer (or reference) to derived class pointer.



Inheritance

Specialization/Overriding member functions



- **Overriding:** same function name, return type and parameter list, defined again in derived classes and different from the base class.
- Different from overloading (same function name, different return type and/or different set of arguments)
- You can still call the member function of base classes, but it seems very rare.

```
Dog d1;  
d1.Animal::speak();
```

- Consider how to apply `virtual` keyword in overriding member functions

```
void Animal::speak() const  
{  
    cout << "..." << endl;  
}
```

```
class Dog : public Animal  
{  
    public:  
        Dog();  
        ~Dog();  
        string getName() const;  
        void setName(string name);  
        void speak() const;  
    private:  
        string m_name;  
};  
  
void Dog::speak() const  
{  
    cout << "Woof!" << endl;  
}
```

Inheritance

Construction

- How to construct a Dog, which is a derived class from Animal?

- Steps:

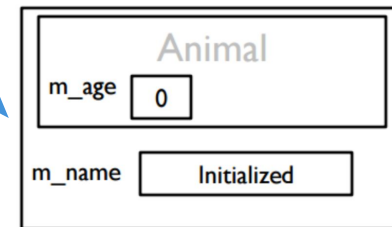
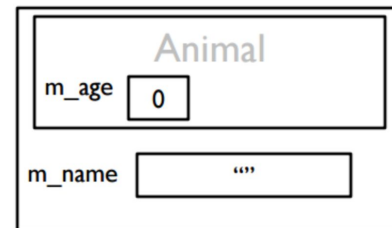
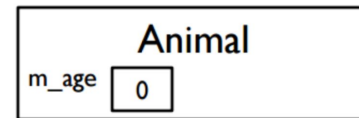
- The **base part of the class** (Animal) is constructed.
- The **member variables** of Dog are constructed.
- The **body of constructor** (Dog) is executed.

```
class Animal
{
public:
    Animal();
    ~Animal();
    int getAge() const;
    void speak() const;
private:
    int m_age;
};
```

base class

```
class Dog : public Animal
{
public:
    Dog();
    ~Dog();
    string getName() const;
    void setName(string name);
private:
    string m_name;
};
```

derived class



- How to overload Dog's constructor to create

`Dog::Dog(string initName, int initAge) ?`

Wrong:

```
Dog::Dog(string initName, int initAge)
:m_age(initAge), m_name(initname)
{ }
```

Correct:

```
Dog::Dog(string initName, int initAge)
:Animal(initAge), m_name(initname)
{ }

class Animal{
public:
    Animal(int initAge);
    ...
}
```

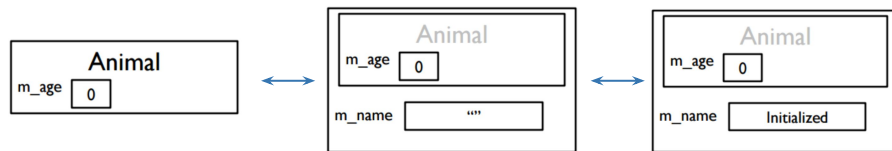
The order of destruction of a derived class: **Just reverse the order of construction.**

Order of construction:

1. Construct the base part, consulting the member initialization list (If not mentioned there, use base class's default constructor)
2. Construct the data members, consulting the member initialization list. (If not mentioned there, use member's default constructor if it's of a class type, else leave uninitialized.)
3. Execute the body of the constructor.

Order of destruction:

1. Execute the body of the destructor.
2. Destroy the data members (doing nothing for members of builtin types).
3. Destroy the base part.



Inheritance: Test Now!

Example: Worksheet 2 Question



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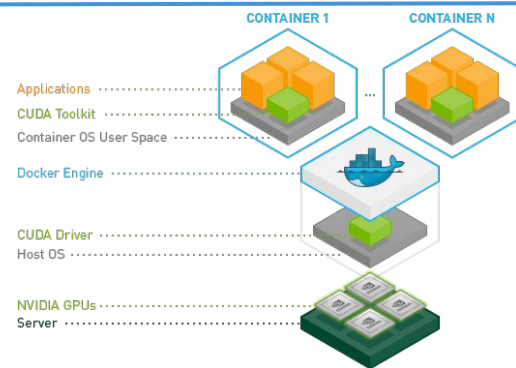
- Pay attention to:
 - Construction and destruction of derived classes and base classes
 - Difference of inherited class and data members

* Philosophy/Inheritance

Another “not-so-related” example

- There are many examples and applications of “inheritance”.
- One example: Commonly-used Docker Images

HIGH PERFORMANCE COMPUTING							
DEEP LEARNING							
MACHINE LEARNING							
INFERENCE							
VISUALIZATION							
INFRASTRUCTURE							
Publisher: All ▾ Search containers							
NAME	REPOSITORY	PUBLISHER	LATEST TAG	MODIFIED	SIZE	BUILT BY	PULL LATEST
Caffe2	nvidia/caffe2	Facebook	18.08-py3	August 27, 2018	1.3 GB	NVIDIA	↓ >
Chainer	partners/chainer	Preferred Ne...	4.0.0b1	December 12, 2017	963.75 MB	Preferred Ne...	↓ >
CUDA	nvidia/cuda	NVIDIA	9.0-devel-ub...	December 14, 2018	1.04 GB	NVIDIA	↓ >
CUDA Sample	nvidia/k8s/cuda-sample	NVIDIA	tbody	June 18, 2018	95.75 MB	NVIDIA	↓ >
Deep Cognition Studio	partners/deep-learning-studio	Deep Cogniti...	cuda9-2.5.0	October 18, 2018	2.03 GB	Deep Cogniti...	↓ >
DIGITS	nvidia/digits	NVIDIA	19.01-caffe	January 24, 2019	1.47 GB	NVIDIA	↓ >
H2O Driverless AI	partners/h2oai-driverless	H2O.ai	latest	March 9, 2018	2 GB	H2O.ai	↓ >
Kinetic	partners/kinetic	Kinetic	cuda9-6.1.0.9	March 22, 2018	5.62 GB	Kinetic	↓ >
MATLAB	partners/matlab	Mathworks	r2018b	February 6, 2019	8.1 GB	Mathworks	↓ >
Microsoft Cognitive Toolkit	nvidia/ctk	Microsoft Res...	18.08-py3	August 27, 2018	2.4 GB	NVIDIA	↓ >
MXNet	nvidia/mxnet	Apache Softw...	19.01-py3	January 24, 2019	1.46 GB	NVIDIA	↓ >
NVCaffe	nvidia/caffe	NVIDIA	19.01-py2	January 24, 2019	1.39 GB	NVIDIA	↓ >
OmniSci (MapD)	partners/mapd	OmniSci	3.2.2	December 1, 2017	662.43 MB	OmniSci	↓ >
PaddlePaddle	partners/paddlepaddle	Baidu	0.11-alpha	December 3, 2017	1.28 GB	Baidu	↓ >
PyTorch	nvidia/pytorch	Facebook	19.01-py3	January 24, 2019	2.7 GB	NVIDIA	↓ >
RAPIDS	nvidia/rapidsai/rapidsai	Open Source	cuda9.2-runti...	January 31, 2019	2.67 GB	NVIDIA	↓ >
TensorFlow	nvidia/tensorflow	Google Brain ...	19.01-py3	January 24, 2019	2.34 GB	NVIDIA	↓ >
TensorRT	nvidia/tensorrt	NVIDIA	19.01-py3	January 24, 2019	1.5 GB	NVIDIA	↓ >
TensorRT Inference Server	nvidia/tensorrtserver	NVIDIA	19.01-py3	January 24, 2019	1.49 GB	NVIDIA	↓ >
Theano	nvidia/theano	University of ...	18.08	August 27, 2018	1.49 GB	NVIDIA	↓ >



Inheritance does not exactly just means base/derived class in C++ programming. It is everywhere.

- Polymorphism is how you make Inheritance truly useful.
- Think about example of dogs and animals. Once I define a function that accepts a (reference or pointer to a) `Animal`, not only can I pass `Animal` variables to that class, But I can also pass any variable that was derived from a `Animal` (such as `Dogs`)!

Polymorphism

Virtual Functions: Examples



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```
class Shape {  
public:  
    virtual double getArea()  
    { return (0); }  
    ...  
private:  
    ...  
};
```

```
class Square: public Shape {  
public:  
    Square(int side){ m_side=side; }  
    virtual double getArea()  
    { return (m_side*m_side); }  
    ...  
private:  
    int m_side;  
};
```

```
class Square: public Shape {  
public:  
    Circle(int rad){ m_rad=rad; }  
    virtual double getArea()  
    { return (3.14*m_rad*m_rad); }  
    ...  
private:  
    int m_rad;  
};
```

```
void PrintPrice(Shape &x)  
{  
    cout << "Cost is: $";  
    cout << x.getArea()*3.25;  
}  
  
int main() {  
    Square s(5);  
    Circle c(10);  
    PrintPrice(s);  
    PrintPrice(c);  
}
```

When you use the `virtual` keyword, C++ figures out what class is being referenced and calls the right function.

Polymorphism works with pointers too.

I will not forget to add `virtual` in front of my destructors when I use inheritance/polymorphism. → *What is the problem if not?*

Polymorphism

Pure Virtual Functions & Abstract Base Class



- Sometimes we have no idea what to implement in base functions. For example, without knowing what the animal is, it is difficult to implement the `speak()` function.
- Solution: Pure virtual functions
- Note:
 - Declare pure virtual functions in the base class. (=0!)
 - Considered as dummy function.
 - The derived class **MUST** implement all the pure virtual functions of its base class.
- If a class has at least one pure virtual function, it is called *abstract base class*.

```
class Shape {  
    public:  
        virtual double getArea()  
        { return (0); }  
    ...  
    private:  
        ...  
};
```

Never actually used!

```
class Animal  
{  
    public:  
        Animal();  
        virtual ~Animal();  
        int getAge() const;  
        virtual void speak() const = 0;  
    private:  
        int m_age;  
};
```

Polymorphism

Cheatsheet from Carey's slides

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You can't access private members of the base class from the derived class:

```
// BAD!  
class Base  
{  
public:  
...  
  
private:  
    int v;  
};  
  
class Derived: public Base  
{  
public:  
    Derived(int q)  
    {  
        v = q; // ERROR!  
    }  
  
    void foo()  
    {  
        v = 10; // ERROR!  
    }  
};
```

```
// GOOD!  
class Base  
{  
public:  
    Base(int x)  
    { v = x; }  
    void setV(int x)  
    { v = x; }  
...  
private:  
    int v;  
};  
  
class Derived: public Base  
{  
public:  
    Derived(int q)  
    : Base(q) // GOOD!  
    {  
        ...  
    }  
  
    void foo()  
    {  
        setV(10); // GOOD!  
    }  
};
```

Always make sure to add a virtual destructor to your base class:

```
// BAD!  
class Base  
{  
public:  
    ~Base() { ... } // BAD!  
};  
  
class Derived: public Base  
{  
...  
};
```

```
// GOOD!  
class Base  
{  
public:  
    virtual ~Base() { ... } // GOOD!  
};  
  
class Derived: public Base  
{  
...  
};
```

```
class Person  
{  
public:  
    virtual void talk(string &s) { ... }  
};  
  
class Professor: public Person  
{  
public:  
    void talk(std::string &s)  
    {  
        cout << "I profess the following: ";  
        Person::talk(s); // uses Person's talk  
    }  
};
```

Don't forget to use **virtual** to define methods in your base class, if you expect to re-define them in your derived class(es)

To call a base-class method that has been re-defined in a derived class, use the **base::** prefix!

So long as you define your BASE version of a function with virtual, all derived versions of the function will automatically be virtual too (even without the virtual keyword)!

Polymorphism

Cheatsheet from Carey's slides (Cont'd)



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```
class SomeBaseClass
{
public:
    virtual void aVirtualFunc() { cout << "I'm virtual"; } // #1
    void notVirtualFunc() { cout << "I'm not"; } // #2
    void tricky() // #3
    {
        aVirtualFunc(); // ***
        notVirtualFunc();
    }
};

class SomeDerivedClass: public SomeBaseClass
{
public:
    void aVirtualFunc() { cout << "Also virtual!"; } // #4
    void notVirtualFunc() { cout << "Still not"; } // #5
};

int main()
{
    SomeDerivedClass d;
    SomeBaseClass *b = &d; // base ptr points to derived obj

    // Example #1
    cout << b->aVirtualFunc(); // calls function #4

    // Example #2
    cout << b->notVirtualFunc(); // calls function #2

    // Example #3
    b->tricky(); // calls func #3 which calls #4 then #2
}
```

Example #1: When you use a BASE pointer to access a DERIVED object, AND you call a VIRTUAL function defined in both the BASE and the DERIVED classes, your code will call the DERIVED version of the function.

Example #2: When you use a BASE pointer to access a DERIVED object, AND you call a NON-VIRTUAL function defined in both the BASE and the DERIVED classes, your code will call the BASE version of the function.

Example #3: When you use a BASE pointer to access a DERIVED object, all function calls to VIRTUAL functions (***) will be directed to the derived object's version, even if the function (tricky) calling the virtual function is NOT VIRTUAL itself.

Recursion

Basics



- Function-writing technique where the functions refers to itself.
- Let's talk about the factorial example again!
 - Similar to mathematical induction → Prove $k=1$ is valid and prove $k=n$ is valid when $k=n-1$ is valid.
 - Base cases are important and need to be carefully considered.

```
int factorial(int n)
{
    int temp = 1;
    for (int i = 1; i <= n; i++)
        temp *= i;
    return temp;
}
```

```
int factorial(int n)
{
    if (n <= 1)
        return 1;

    return n * factorial(n - 1);
}
```

Without explicit loops!

- Step 1: Find the base case(s).
 - What are the trivial cases? Eg. empty string, empty array, single-item subarray.
 - When should the recursion stop?
- Step 2: Decompose the problem.
 - Take tail recursion as example.

- Take the first (or last) of the n items of information
- Make a recursive call to the rest of $(n-1)$ items. The recursive call will give you the correct results.
- Given this result and the information you have on the first (or last item) conclude about current n items.

- Step 3: Just solve it! (*Well, easier said than done~*)

Recursion

Practice Examples



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- Practice: Print out the permutations of a given vector.

Input: [1,2,3]

Output: [1,2,3], [1,3,2], [2,1,3], [2,3,1], [3,1,2], [3,2,1]

Implement: `void permutation(vector<int>& nums, int start);`

- Note: Some data structures are easy to implement recursive technique: arrays, trees (will be discussed later).



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Thank you!

Q & A

Exercise problems from Worksheet 1 & 2 (see “LA worksheet” tab in CS32 website).

Questions today:

- Worksheet 3 Question 5, 12, 13

Answers will be posted after discussions.