ECE 220 Computer Systems & Programming

Lecture 21 – Overloading, Inheritance & Polymorphism

Adapted from Prof. Moon

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Operator Overloading
another example: replace function add( )

```
#include <iostream>
#include<cmath>

//Example: a class in CPP, which has 2 members: angle and length
class vector{
private:
        double angle;
        double length;
//Constructor
public:
        vector(double a, double l){
        angle=a;
        length=l;
        }
//Default Constructor
vector(){angle=0.0; length=0.0;}

//function scaleVector to scale the length of a vector
void scaleVector(double alpha) {
        length *= alpha;
 }

void printVector()
{
std::cout<<"Vector length is: "<<length<<std::endl;
std::cout<<"Vector angle is: "<< angle<<std::endl;
}
```

```
vector add(vector b)
{
vector c;
double ax=length*cos(angle);
double bx=b.length*cos(b.angle);
double ay=length*sin(angle);
double by=b.length*sin(b.angle);
c.length=sqrt((ax+bx)*(ax+bx)+(ay+by)*(ay+by));
c.angle=atan((ay+by)/(ax+bx));
return c;
}

};
```

```
int main(){
        vector a = {0.50,1};
        vector *d=&a;

// no access to the private member
//use C++ methods/functions

d->scaleVector(5.0);
d->printVector();
vector b = {1.0, 2.0};
vector c = a.add(b);
        c.printVector();
        return 0;
}
```

Operator Overloading
another example: replace function add( )

```
int main(){
        vector a = {0.50,1};
        vector *d=&a;
//use C++ methods/functions
        d->scaleVector(5.0);
        d->printVector();

vector b = {1.0, 2.0};
vector c = a+b;
        c.printVector();
        return 0;
}
```

```
int main(){
        vector a = {0.50,1};
        vector *d=&a;

// no access to the private member
//use C++ methods/functions

d->scaleVector(5.0);
d->printVector();
vector b = {1.0, 2.0};
vector c = a.add(b);
        c.printVector();
        return 0;
}
```

```
vector add(vector b)
{
vector c;
double ax=length*cos(angle);
double bx=b.length*cos(b.angle);
double ay=length*sin(angle);
double by=b.length*sin(b.angle);
c.length=sqrt((ax+bx)*(ax+bx)+(ay+by)*(ay+by));
c.angle=atan((ay+by)/(ax+bx));
return c;
}

};
```

```
vector operator+(vector b)
{
vector c;
double ax=length*cos(angle);
double bx=b.length*cos(b.angle);
double ay=length*sin(angle);
double by=b.length*sin(b.angle);
c.length=sqrt((ax+bx)*(ax+bx)+(ay+by)*(ay+by));
c.angle=atan((ay+by)/(ax+bx));
return c;
}

};
```

Constructor

```
class Person{
    char name[20];
    int age;

public:

    Person(char const *_name, int _age);
    Person(){};
    void ShowData();
};
Person::Person(char const *_name, int _age){
    strcpy(name, _name);
    age = _age;
}
int main(){
//    Person p = {"Alice", 20};
    Person p("Alice", 20);
}
```

Or `Person p = Person("Alice", 20);`

Arrays & Pointers & Objects

- Array of objects

```
Person p[2] = {Person("Alice", 20), Person("Bob", 22) };
p[0].ShowData();
p[1].ShowData();
```

- Array of pointers to objects

```
Person *ptr[2];
ptr[0] = new Person("Alice",20);
ptr[1] = new Person("Bob",22);
ptr[0]->ShowData();
ptr[1]->ShowData();
```

- Reference to objects

```
Person &ref = *ptr[0];
ref.ShowData();
```

```
Person &ref = p[0];
ref.ShowData();
```

C++

- **Object Oriented Programming** (OOP)
  Programming style associated with **class** and **objects** and other concepts like
  - Encapsulation
  - Inheritance
  - Polymorphism
  - Abstraction

Inheritance – Why?

```
class Airplane{
    private:
    int passenger;
    double baggage;
    int crew_man;
    public:
    Airplane(int person, double weight, int crew){
        passenger = person;
        baggage = weight;
        crew_man = crew;
    }
    void Ride(int person){
        passenger += person;
    }
    void Load(double weight){
        baggage += weight;
    }
    void TakeCrew(int crew){
        crew_man += crew;
    }
};
```

```
class Train{
    private:
    int passenger;
    double baggage;
    int length;
    public:
    Train(int person, double weight, int len){
        passenger = person;
        baggage = weight;
        length = len;
    }
    void Ride(int person){
        passenger += person;
    }
    void Load(double weight){
        baggage += weight;
    }
    void AddLength(int len){
        length += len;
    }
};
```

‘Airplane’ and ‘Train’ share many data and functions!

Inheritance

base class

```
class Vehicle{
private:
   int passenger;
   double baggage;
public:
   void Ride(int person){passenger += person;}
   void Load(double weight){baggage += weight;}
   int getPassenger(){ return passenger;}
   double getBaggage(){ return baggage;}
};
```

Airplane class is inherited from Vehicle class.

derived class

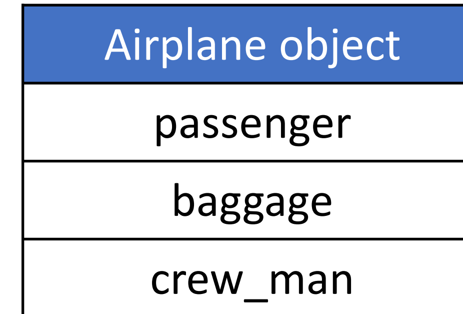
```
class Airplane : public Vehicle{
private:
   int crew_man;
public:
   Airplane(int crew) {crew_man = crew;}
   void TakeCrew(int crew){crew_man += crew;}
   int getCrew(){  return crew_man;}
   void ShowData(){
      cout<<"<<Airplane>> "<<endl;
      cout<<"passenger: "<<getPassenger()<<endl;
      cout<<"baggage: "<<getBaggage()<<endl;
      cout<<"crew man: "<<getCrew()<<endl;
   }
};
```

Inheritance

```
int main(){
    Airplane a(10);
    a.ShowData();
}
```

Vehicle's member

Airplane's member




```
<<Airplane>>
passenger: 4196928
baggage: 2.07321e-317
crew man: 10
```

How do we initialize the members from the base class?

compile error!
because the members are private.

```
Airplane(int person, double weight, int crew) {
    passenger = person;
    baggage = weight;
    crew_man = crew;
}
```

Constructors: Base vs Derived

```
class Base{
  public:
    Base(){
      cout<<"Base() called."<<endl;
    }
    Base(int a){
      cout<<"Base(int a) called."<<endl;
    }
};
class Derived: public Base{
  public:
    Derived(){
      cout<<"Derived() called."<<endl;
    }
    Derived(int a){
      cout<<"Derived(int a) called."<<endl;
    }
};
```

```
int main(){
  cout<<"<<d1 declared.>>"<<endl;
  Derived d1;
  cout<<"<<d2 declared.>>"<<endl;
  Derived d2(1);
}
```

```
<<d1 declared.>>
Base() called.
Derived() called.

<<d2 declared.>>
Base() called.
Derived(int a) called.
```

1. The base constructor is called, then the derived one.
2. The default constructor is called for the base class.

How can we call Base(int a)?

Constructors: Base vs Derived

```
class Base{
  public:
    Base(){
      cout<<"Base() called."<<endl;
    }
    Base(int a){
      cout<<"Base(int a) called."<<endl;
    }
};
class Derived: public Base{
  public:
    Derived(){
      cout<<"Derived() called."<<endl;
    }
    Derived(int a): Base(a){
      cout<<"Derived(int a) called."<<endl;
    }
};
```

```
int main(){
  cout<<"<<d1 declared.>>"<<endl;
  Derived d1;
  cout<<"<<d2 declared.>>"<<endl;
  Derived d2(1);
}
```

```
<<d1 declared.>>
Base() called.
Derived() called.
<<d2 declared.>>
Base(int a) called.
Derived(int a) called.
```

Initializer list

Call the base class constructor that has one integer argument.

1. Initialize Base members: Initializer List

```
class Vehicle{
   int passenger;
   double baggage;
public:
   Vehicle(int person, double weight){
      passenger = person;
      baggage = weight;
   }
              . . .
};

class Airplane : public Vehicle{
   int crew_man;
public:
   Airplane(int person, double weight, int crew): Vehicle(person, weight) {
      crew_man = crew;
   }
              . . .
};


int main(){
   Airplane a(120, 1300.0, 10);
   a.ShowData();
}
```

When this constructor is called,
we will first call
Vehicle(int person, double weight).

<<Airplane>>
passenger: 120
baggage: 1300
crew man: 10

1. Initialize Base members: Initializer List

```
class Airplane : public Vehicle{
   int crew_man;
public:
   Airplane(int p, double w, int c): Vehicle(p, w) {
      crew_man = c;
   }
               . . .
};
```

```
int x;
x = 10;
```

```
class Airplane : public Vehicle{
   int crew_man;
public:
   Airplane(int p, double w, int c): Vehicle(p, w), crew_man(c) {
   }
               . . .
};
```

```
int x = 10;
```

You can also use Initializer List for the data member

2. Initialize Base members: Protected Member

```
class Vehicle{
protected:
    int passenger;
    double baggage;
public:
    Vehicle(){}
            . . .
};

class Airplane : public Vehicle{
    int crew_man;
public:
    Airplane(int person, double weight, int crew){
        passenger = person;
        baggage = weight;
        crew_man = crew;
    }
            . . .
};
```

Access	public members	protected members	private members
Same Class	Y	Y	Y
Derived Class	Y	Y	N
Outside Class	Y	N	N

Protected members of a class A are not accessible outside of A's code, but is accessible from the code of any class derived from A.

Inheritance Another Example:

```
#include <iostream>      // used for IO
#include<cmath>

using namespace std;     // creates textual container for
                         // variables and functions
//Example: a class in CPP, which has 2 members: angle and length
class vector{
protected:
        double angle;
        double length;
//Constructor
public:
        vector(double a, double l){
        angle=a;
        length=l;
        }
//Default Constructor
vector(){angle=0.0; length=0.0;}

//function scaleVector to scale the length of a vector
void scaleVector(double alpha) {
        length *= alpha;
 }
```

```
void printVector()
{
cout<<"Vector length is: "<<length<<endl;
cout<<"Vector angle is: "<< angle<<endl;
}
```

```
vector operator+(vector b)
{
vector c;
double ax=length*cos(angle);
double bx=b.length*cos(b.angle);
double ay=length*sin(angle);
double by=b.length*sin(b.angle);
c.length=sqrt((ax+bx)*(ax+bx)+(ay+by)*(ay+by));
c.angle=atan((ay+by)/(ax+bx));
return c;
}
};
```

```
class orthovector: public vector
 {
 protected:
          int d;
 public:
        orthovector(int dir, double l) {  // dir is 0,1,2,3
                         // indicating right, up, left, down
          const double halfPI = 1.507963268;
          d = dir;
          angle = d*halfPI;
          length = l;
        }

        orthovector() { d = 0; angle = 0.0; length = 0.0; }
        double hypotenuse(orthovector b);
};
 double orthovector::hypotenuse(orthovector b) {
        if( (d+b.d)%2 == 0 )
          {if (d==b.d)
            return length+b.length;
            else
                return abs(length-b.length);
          }
        return (sqrt( length*length + b.length*b.length ) );
 }
```

```cpp
int main()
{
 orthovector c(1,1);
 orthovector d(1,4);
 vector e = c+d; //add returns a vector type
 e.printVector();

 double f = c.hypotenuse(d);
 cout << "f hypotenuse is " << f <<endl;
}
```

```cpp
#include <iostream>     // used for IO
#include<cmath>

using namespace std;    // creates textual container for
                        // variables and functions
//Example: a class in CPP, which has 2 members: angle and length
class vector{
protected:
        double angle;
        double length;
//Constructor
public:
        vector(double a, double l){
        angle=a;
        length=l;
        }
//Default Constructor
vector(){angle=0.0; length=0.0;}

//function scaleVector to scale the length of a vector
void scaleVector(double alpha) {
        length *= alpha;
 }
```

```cpp
vector operator+(vector b)
{
vector c;
double ax=length*cos(angle);
double bx=b.length*cos(b.angle);
double ay=length*sin(angle);
double by=b.length*sin(b.angle);
c.length=sqrt((ax+bx)*(ax+bx)+(ay+by)*(ay+by));
c.angle=atan((ay+by)/(ax+bx));
return c;
}
};
```

```cpp
class orthovector: public vector
 {
 protected:
           int d;
 public:
         orthovector(int dir, double l) {  // dir is 0,1,2,3
                                 // indicating right, up, left, down
           const double halfPI = 1.507963268;
           d = dir;
           angle = d*halfPI;
           length = l;
         }

         orthovector() { d = 0; angle = 0.0; length = 0.0; }
         double hypotenuse(orthovector b);
};
 double orthovector::hypotenuse(orthovector b) {
        if( (d+b.d)%2 == 0 )
           {if (d==b.d)
             return length+b.length;
             else
                  return abs(length-b.length);
           }
        return (sqrt( length*length + b.length*b.length ) );
 }
```

Polymorphism

- A call to a member function will cause a different function to be executed depending on the type of the object that invokes the function.
- Function overriding allows to have the same function in derived class which is already defined in its base class.

```
class Vehicle{
   public:
   void ShowData(){cout<<"<<Vehicle>> "<<endl;}
};
class Airplane : public Vehicle{
   public:
   void ShowData(){cout<<"<<Airplane>> "<<endl;}
};
class Train : public Vehicle{
   public:
   void ShowData(){cout<<"<<Train>> "<<endl;}
};
```

```
int main(){
   Airplane a(100,300,20);
   a.ShowData();
}
```

```
<<Airplane>>
```

Airplane::ShowData() overrides Vehicle::ShowData().

Declared Type vs. Actual Type

```
int main(){
    Airplane a(100,300,20);
    Train t(50,100,30);

    a.ShowData();                    <<Airplane>>
    t.ShowData();                    <<Train>>

    Vehicle *ptr;
    ptr = &a;
    ptr->ShowData();                 <<Vehicle>>

    ptr = &t;
    ptr->ShowData();                 <<Vehicle>>

    //ptr->AddLength(10);              Compile Error!
}
```

- Base class pointer (or reference) can point its derived class.
- However, the base class does not have access to its derived class members.

Virtual Function – Why?

```
class City{
   private:
      Vehicle *vlist[100];
      int index;
   public:
      City(){ index = 0;}
      void AddVehicle(Vehicle *v){
         vlist[index++] = v;
      }
      void ShowList(){
         for(int i=0;i<index;i++)
            vlist[i]->ShowData();
      }
};
```

```
int main(){
   City Champaign;

   Champaign.AddVehicle(new Airplane(30,100,5));
   Champaign.AddVehicle(new Train(100,300,10));
   Champaign.AddVehicle(new Train(130,300,15));

   Champaign.ShowList();
}
```

Virtual Function – Why?

```
class City{
  private:
    Vehicle *vlist[100];
    int index;
  public:
    City(){ index = 0;}
    void AddVehicle(Vehicle *v){
      vlist[index++] = v;
    }
    void ShowList(){
      for(int i=0;i<index;i++)
        vlist[i]->ShowData();
    }
};
```

```
int main(){
  City Champaign;

  Champaign.AddVehicle(new Airplane(30,100,5));
  Champaign.AddVehicle(new Train(100,300,10));
  Champaign.AddVehicle(new Train(130,300,15));

  Champaign.ShowList();
}
```

We want to print out the full information about Airplane or Train.

But, it will only print out Vehicle.

We want to manage *base class*, not *derived classes*.

→ Wish to resolve functions at run-time, a.k.a. dynamic binding.

Virtual Function

- Virtual functions are the member function in the base class that is expected to **be redefined in the derived class**.

```
class Vehicle{
   public:
   virtual void ShowData(){
      cout<<"<<Vehicle>> "<<endl;
   }
};
class Airplane : public Vehicle{
   public:
   void ShowData(){
      cout<<"<<Airplane>> "<<endl;
   }
};
class Train : public Vehicle{
   public:
   void ShowData(){
      cout<<"<<Train>> "<<endl;
   }
};
```

```
int main(){
   Airplane a(100,300,20);
   Train t(50,100,30);

   a.ShowData();
   t.ShowData();

   Vehicle *ptr;
   ptr = &a;
   ptr->ShowData();

   ptr = &t;
   ptr->ShowData();
}
```

Abstraction – Pure Virtual Function & Abstract Class

- ‘Vehicle’ class will never be instantiated as it is. Instead, it will be either ‘Airplane’ or ‘Train’ object.
- Abstract class cannot be instantiated (pointer is fine) and implemented with one or more “pure” virtual function

```
class Vehicle{                 <=  abstract class (has a pure virtual function)
   public:
   virtual void ShowData() = 0;              <=  pure virtual function (has no body)
};
class Airplane : public Vehicle{
   public:
   void ShowData(){
      cout<<"<<Airplane>> "<<endl;
   }
};
class Train : public Vehicle{
   public:
   void ShowData(){
      cout<<"<<Train>> "<<endl;
   }
};
```

```
int main(){
   Vehicle *vptr;              // this is ok
   Vehicle v(100,10);          // compile error
}
```

*Derived class must define a body for the pure virtual function, otherwise it will also be considered an abstract base class.

Constructor & Destructor

```
class Person{
    char name[20];
    int age;
public:
    Person(char const *_name, int _age){
        strcpy(name, _name);
        age = _age;
        cout<<"constructing name: "<<name<<endl;
    };
    ~Person(){
        cout<<"destroying name: "<<name<<endl;
    };
};

int main(){
    Person p1 = Person("Alice", 20);
    Person p2 = Person("Bob", 20);
}
```

```
constructing name: Alice
constructing name: Bob
destroying name: Bob
destroying name: Alice
```

Copy Constructor

- Initialize an object using another object (member-by-member).
- If a copy constructor is not provided by the user,
  it will be automatically inserted (<u>default copy constructor</u>)

```
class Point{
private:
    int x,y;
public:
    Point(int _x, int _y){x = _x; y = _y;}
    Point(const Point &p){
        x = p.x;
        y = p.y;
        //p.x = 0; // Don't want to allow this
    }
    void ShowData(){ cout<<"("<<x<<", "<<y<<")"<<endl;}
};
int main(){
    Point p1(10,20);
    Point p2(p1);

    p1.ShowData();
    p2.ShowData();
}
```

Shallow Copy

```
class Person{
    private:
    char *name;
    int age;
    public:
    Person(){};
    Person(const char *_name, int _age);
    void ShowData();
    ~Person();
};
Person::Person(const char *_name, int _age){
    name = new char[strlen(_name)+1];
    strcpy(name, _name);
    age = _age;
}
Person::~Person(){
    delete []name;
}
```

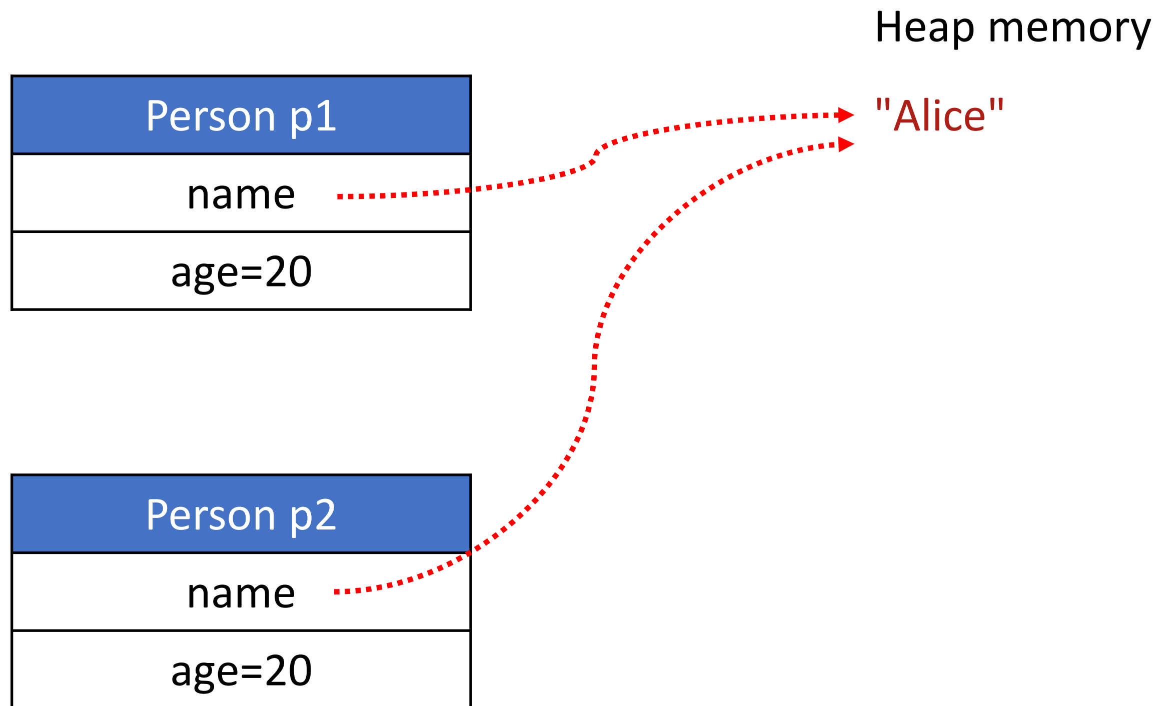
```
int main(){
    Person p1 = Person("Alice", 20);
    Person p2(p1);
    p1.ShowData();
    p2.ShowData();
}
```

Default copy constructor will be inserted.

```
Person::Person(const Person &p){
    name = p.name;
    age = p.age;
}
```

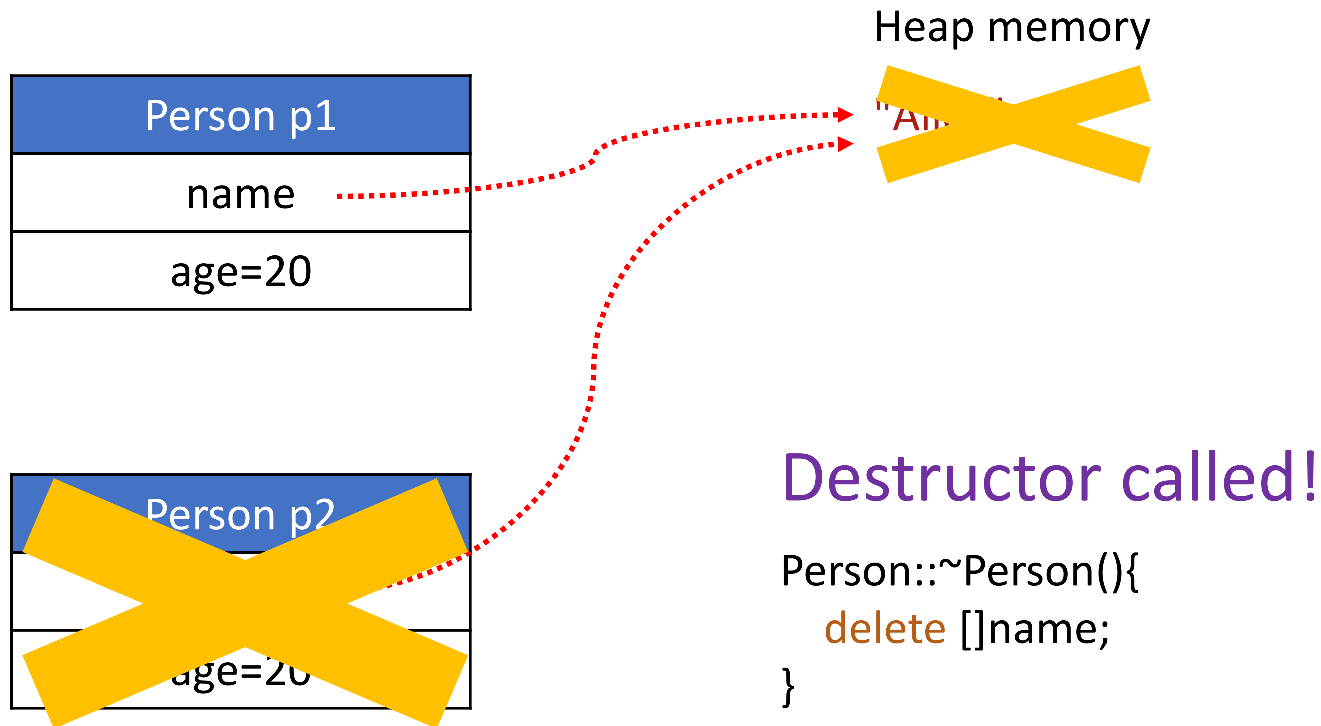
Run-time error!

Shallow Copy




```
Person::Person(const Person &p){
   name = p.name;
   age = p.age;
}
```

Shallow Copy



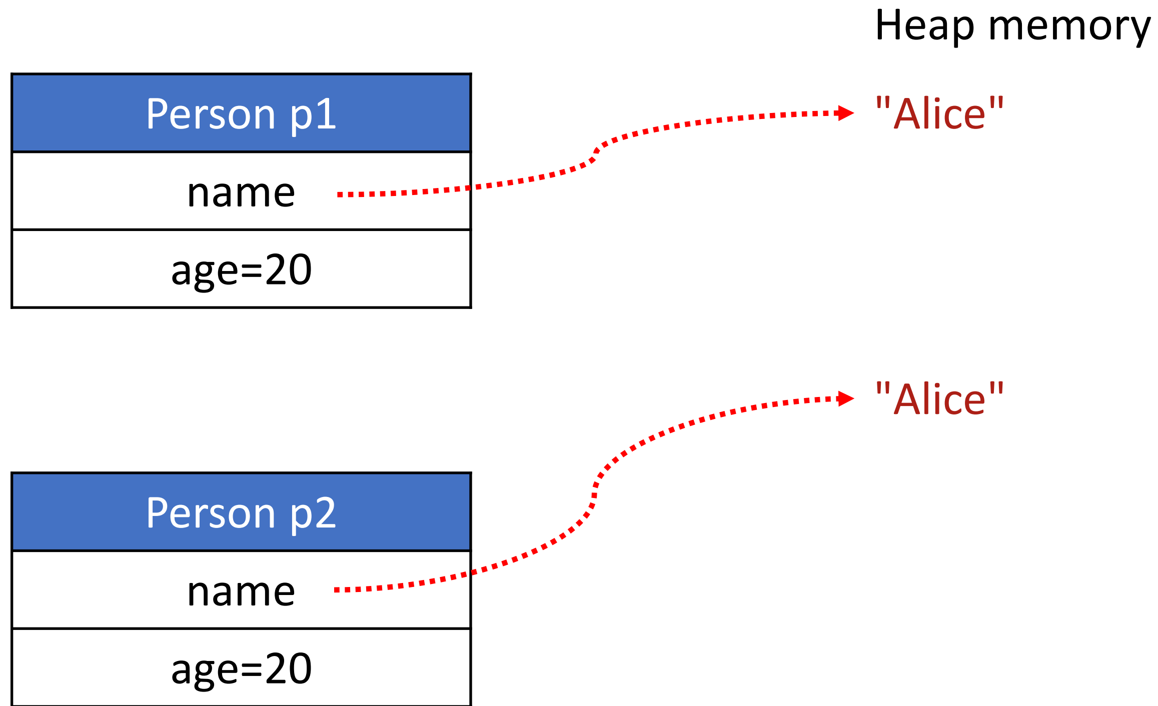
Destructor called!

```
Person::~Person(){
    delete []name;
}
```

When p1 calls its destructor,
the heap memory pointed by “name” is already deallocated.

⃠ double free!

Deep Copy




```
Person::Person(const Person &p){
   name = p.name;
   age = p.age;
}
```

```
Person::Person(const Person &p){
   name = new char[strlen(p.name)+1];
   strcpy(name, p.name);
   age = p.age;
}
```