Copy Ctor

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problem

- For the code below

```
void f() {
     Stash students();
     …
}
```

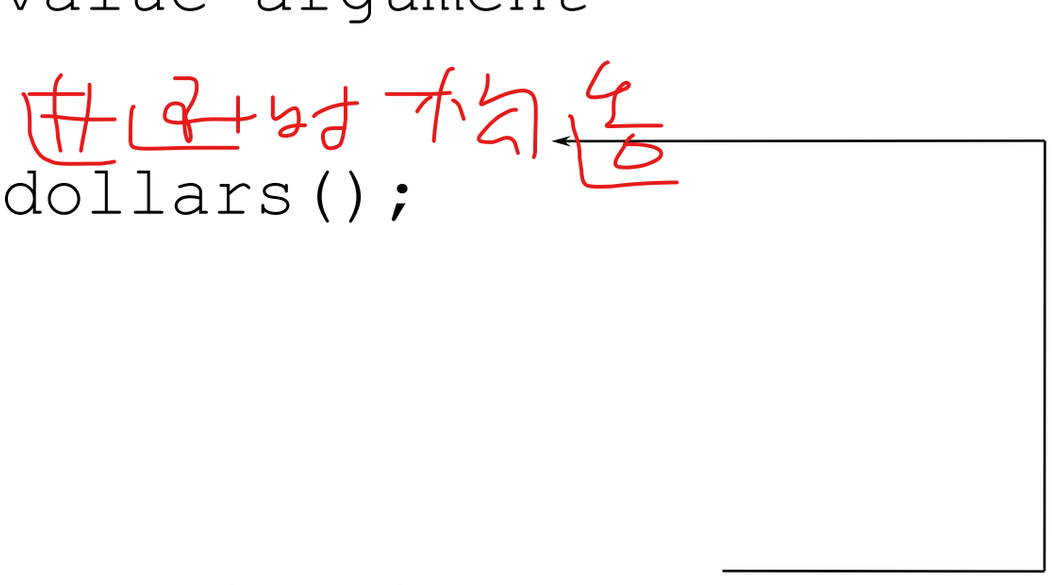
Which statement is RIGHT for the line in function f()?

1. This is a variable definition, while students is an object of Stash, initialized w/ default ctor. with
2. This is a function prototype, while students is a function returns an object of Stash. 函数原型声明
3. This is a function call.
4. This is illegal in C++.

Copying

- Create a new object from an existing one
  - For example, when calling a function

```
// Currency as pass-by-value argument
void func(Currency p) {
    cout << "X = " << p.dollars();
}
...
Currency bucks(100, 0);
func(bucks); // bucks is copied into p
```



Example: HowMany.cpp

The copy constructor

- Copying is implemented by the ***copy constructor***
- Has the unique signature

```
T::T(const T&);
```

  - Call-by-reference is used for the explicit argument
- C++ builds a copy ctor for you if you don't provide one!
  - Copies each member variable
    - Good for numbers, objects, arrays
  - Copies each pointer
    - Data may become shared!
- Example: HowMany2.cpp

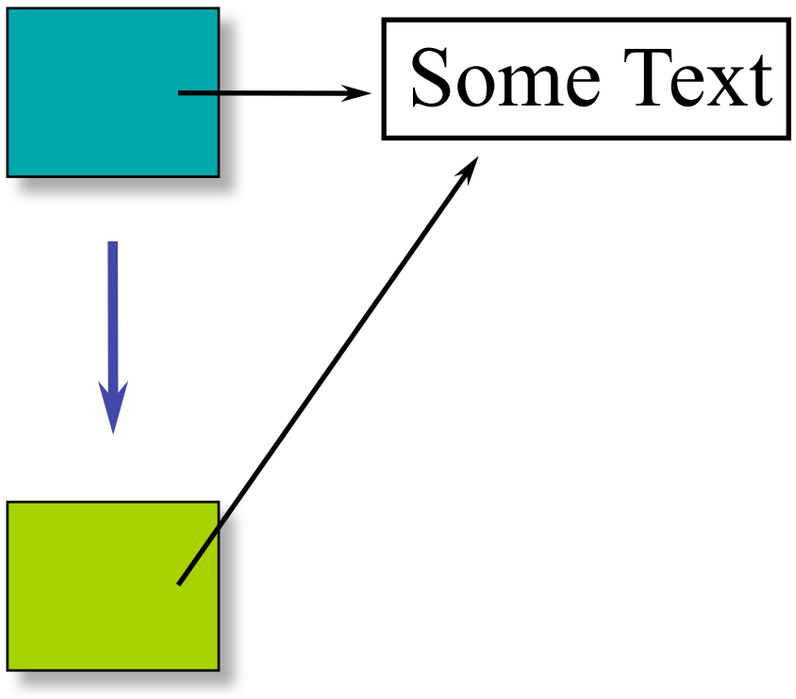
What if class contains pointers?

```
class Person {
public:
    Person(const char *s);
    ~Person();
    void print();
    // ... accessor functions
private:
    char *name;    // char * instead of string
    //... more info e.g. age, address, phone
};
```

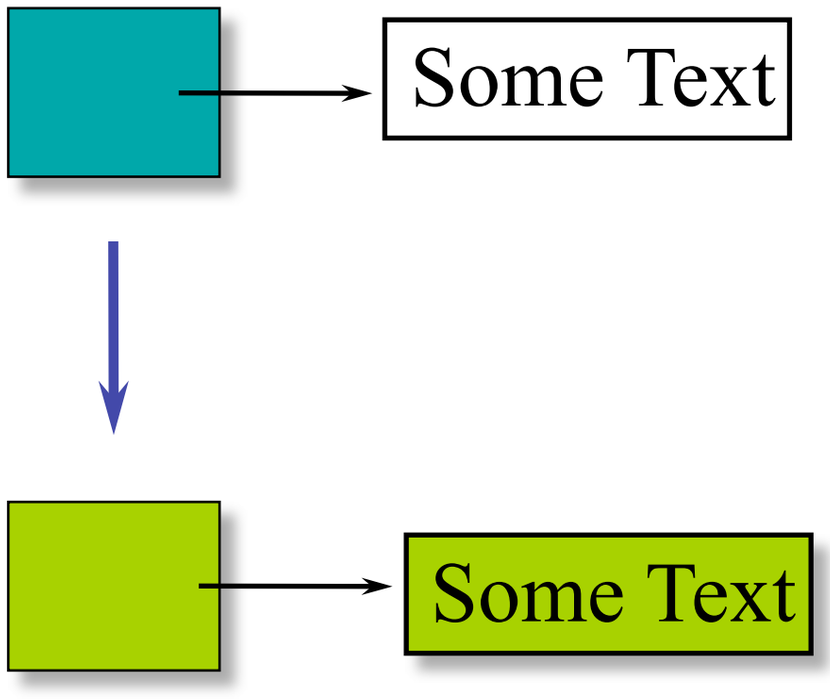
See: Person.h, Person.cpp

Choices

Copy pointer

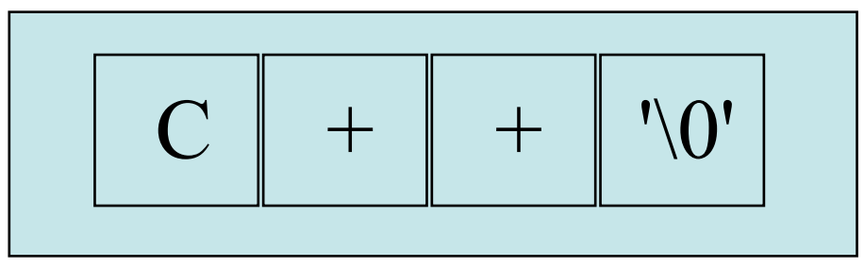


Copy entire block



Character strings

- In C++, a character string is
  - An array of characters
  - With a special terminator — '\0' or ASCII null
- The string "C++" is represented, in memory, by an array of *four* (4, count'em) characters



Standard C library String fxns

- Declared in `<cstring>`

```
size_t strlen(const char *s);
```

  - s is a null-terminated string
  - returns the length of s
  - length does not include the terminator!

```
char *strcpy (char *dest, const char *src);
```

  - Copies src to dest stopping after the terminating null-character is copied. (src should be null-terminated!)
  - dest should have enough memory space allocated to contain src string.
  - Return Value: returns dest

Person (char*) implementation

```
#include <cstring>      // #include <string.h>
using namespace std;

Person::Person( const char *s ) {
  name = new char[::strlen(s) + 1];
  ::strcpy(name, s);
}

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

Person copy constructor

- To Person declaration add copy ctor prototype:

```
Person( const Person& w );   // copy ctor
```

- To Person .cpp add copy ctor defintion:

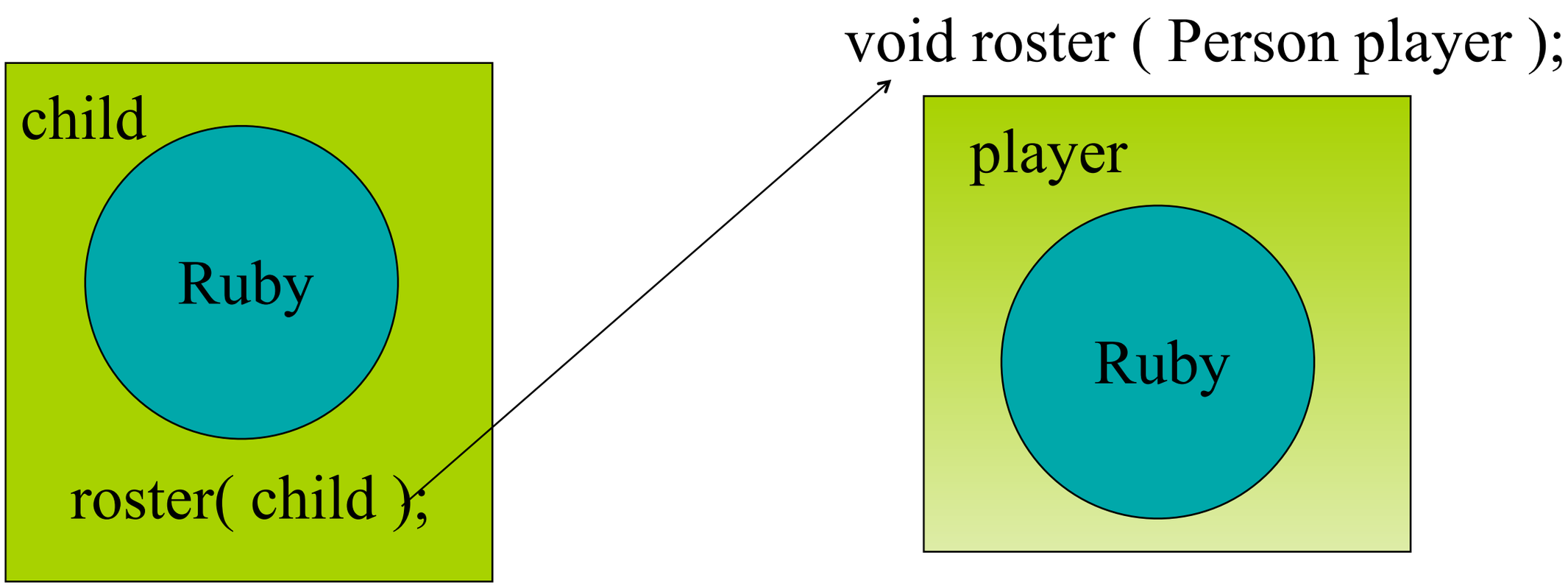
```
Person::Person( const Person& w ) {
    name = new char[::strlen(w.name) + 1];
    ::strcpy(name, w.name);
}
```

- No value returned
- Accesses `w.name` across client boundary
- The copy ctor initializes uninitialized memory

When are copy ctors called?

- During call by value

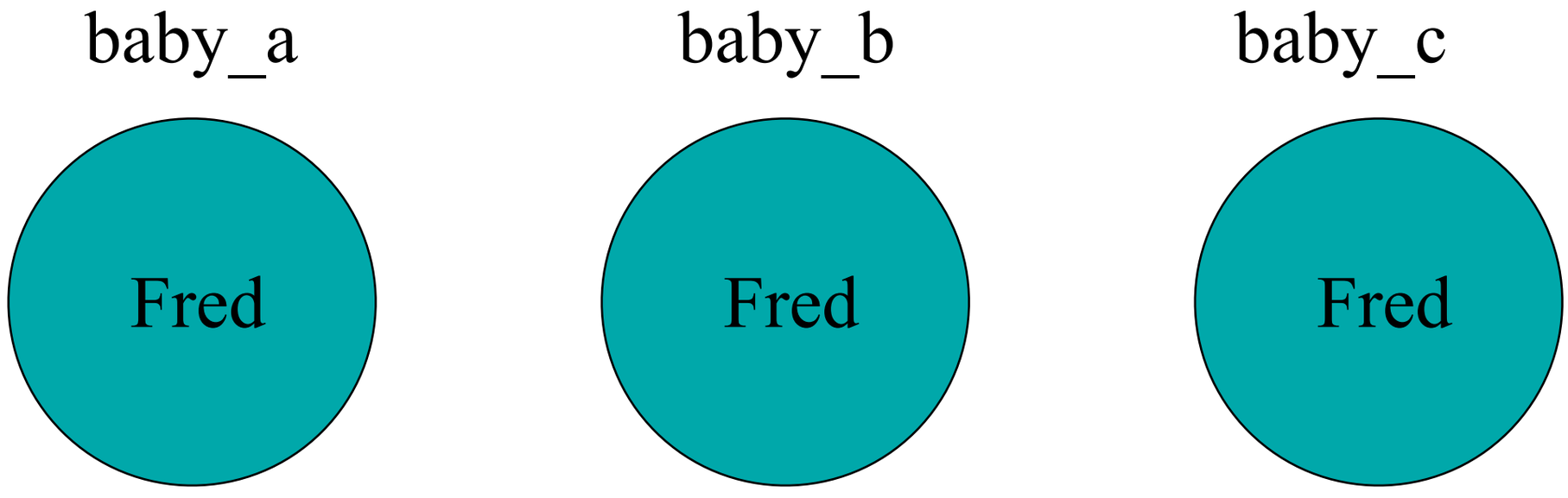
```
void roster( Person );          // declare
  function
Person child( "Ruby" );         // create object
roster( child );              // call function
```



When are copy ctors called?

- During initialization

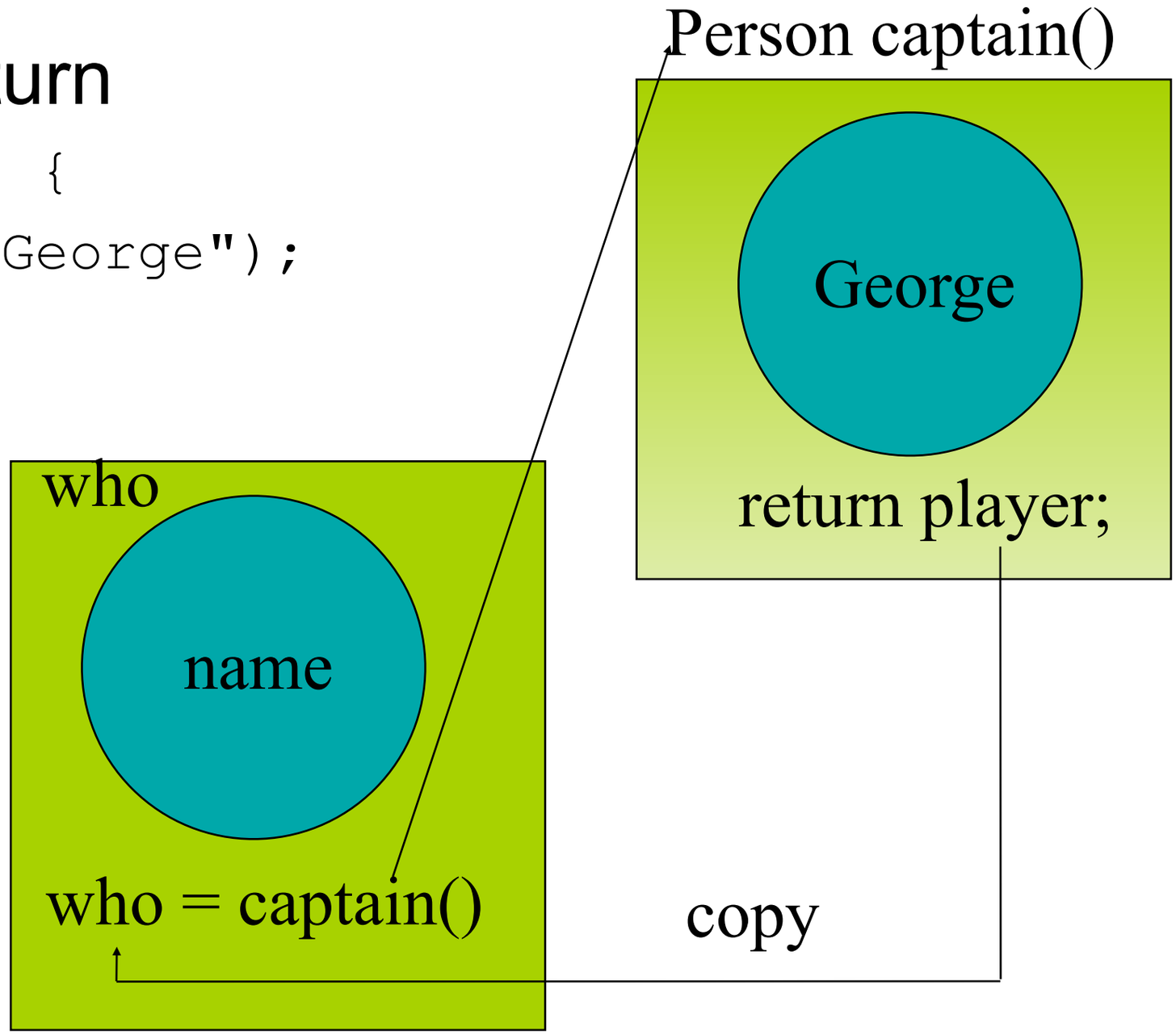
```
Person baby_a("Fred");
// these use the copy ctor
Person baby_b = baby_a;    // not an assignment
Person baby_c( baby_a );   // not an assignment
```



When are copy ctors called?

- During function return

```
Person captain()  {
   Person player("George");
   return player;
}
...
Person who("")
...
```



Person who = captain()的话有两次拷贝构造
who = captain()的话一次拷贝构造+一次拷贝赋值

Copies and overhead

- Compilers can "optimize out" copies when safe!
- Programmers need to
  - –Program for "dumb" compilers
  - –Be ready to look for optimizations

Example

```
Person copy_func( char *who ) {
    Person local( who );
    local.print();
    return local; // copy ctor called!
}

Person nocopy_func( char *who ) {
   return Person( who );
} // no copy needed!
```

中间没有发生变化，优化

Constructions vs. assignment

- Every object is constructed once
- Every object should be destroyed once
  - Failure to invoke delete()
  - Invoking delete() more than once
- Once an object is constructed, it can be the target of many assignment operations

Person: string name

- What if the name was a string (and not a char*)

```
#include <string>
class Person {
public:
    Person( const string& );
    ~Person();
    void print();
    // ... other accessor fxns ...
private:
    string name;                    // embedded object (composition)
    // ... other data members...
};
```

嵌入的对象

Person: string name...

- In the default copy ctor, the compiler recursively calls the copy ctors for all member objects (and base classes).
- default is memberwise initialization

- Example: DefaultCopyConstructor.cpp

Copy ctor guidelines

- In general, be explicit
  - –Create your own copy ctor -- don't rely on the default
- If you don't need one declare a private copy ctor
  - –prevents creation of a default copy constructor
  - –generates a compiler error if try to pass-by-value
  - –don't need a defintion
- Example: NoCopyConstruction.cpp

Overloaded Operators

Overloading Operators

- Allows user-defined types to act like built in types
- Another way to make a function call.

内置

一元、二元

Overloaded operators

Unary and binary operators can be overloaded:

```
+   -   *   /   %   ^    &   |   ~
=   <   >  +=   -=   *=   /=   %=
^=  &=  |=  <<  >>   >>=  <<=  ==
!=  <=  >=  !  &&  ||  ++   --
,   ->*  ->  ()   []
```

operator new　　operator delete

operator new[]　operator delete[]

Operators you can't overload

. .* :: ?:

sizeof typeid

static_cast dynamic_cast const_cast

reinterpret_cast

Restrictions

- Only existing operators can be overloaded (you can't create a ** operator for exponentiation) 求幂
- Operators must be overloaded on a class or enumeration type
- Overloaded operators must
  - Preserve number of operands 保留操作数，加法是二元运算
  - Preserve precedence 保留优先级，加法和乘法

C++ overloaded operator

- Just a function with an operator name!
  - Use the `operator` keyword as a prefix to name

    `operator *(...)`
- Can be a member function
  - Implicit first argument

    const，不能作左值

    ```
    const String String::operator +(const String& that);
    ```
- Can be a global (free) function
  - Both arguments explicit

    ```
    const String operator+(const String& r, const String& l);
    ```

How to overload

- As member function
  - Implicit first argument
  - No type conversion performed on receiver
  - Must have access to class definition

Operators as member functions

```
class Integer {
public:
   Integer( int n = 0 ) : i(n) {}
   const Integer operator+(const Integer& n) const{
       return Integer(i + n.i);
   }
   ...
private:
    int i;
};
```

See: OperatorOverloadingSyntax.cpp

Member Functions

```
Integer x(1), y(5), z;
x + y;     ====> x.operator+(y);
```

- Implicit first argument
- Developer must have access to class definition
- Members have full access to all data in class
- No type conversion performed on receiver

```
z = x + y;   √
z = x + 3;   √
z = 3 + y;
```

x是receiver，y是developer

```
z = x + y;   x.operator+(y)
z = x + 3;   x.operator+(Integer(3))
z = 3 + y;
```

Member Functions...

- For binary operators (+, -, *, etc) member functions require one argument.
- For unary operators (unary -, !, etc) member functions require no arguments:

```
const Integer operator-() const {
   return Integer(-i);
}
...
z = -x;  // z.operator=(x.operator-());
```

How to overload

- As a global function
  - Explicit first argument
  - Type conversions performed on both arguments
  - Can be made a friend

Operator as a global function

```
const Integer operator+(
                const Integer& rhs,
                const Integer& lhs);
Integer x, y;
x + y       ====> operator+(x, y);
```

- Explicit first argument
- Developer does not need special access to classes
- May need to be a friend
- Type conversions performed on both arguments

Global operators (friend)

```
class Integer {
  friend const Integer operator+ (
                const Integer& lhs,
                const Integer& rhs);
    ...
  }
  const Integer operator+(
                const Integer& lhs,
                const Integer& rhs){
     return Integer( lhs.i + rhs.i );
  }
```

friend关键字的作用是允许一个非成员函数（operator+)）访问类的私有成员。

Global Operators

- binary operators require two arguments
- unary operators require one argument
- conversion:

```
z = x + y;
z = x + 3;
z = 3 + y;
z = 3 + 7;
```

- If you don't have access to private data members, then the global function must use the public interface (e.g. accessors)

Tips:Members vs. Free Functions

- Unary operators should be members
- = () [] -> ->* must be members
- assignment operators should be members
- All other binary operators as non-members

Argument Passing

- if it is read-only pass it in as a const reference (except built-ins)
- make member functions const that don't change the class (boolean operators, +, -, etc)
- for global functions, if the left-hand side changes pass as a reference (assignment operators)

对于全局函数中的赋值运算符，如果你打算在函数内部修改左操作数并使其保持修改后的值，应该将左操作数声明为非常量引用（MyClass& lhs）。

Return Values

- Select the return type depending on the expected meaning of the operator. For example,
  - For operator+ you need to generate a new object. Return as a const object so the result cannot be modified as an lvalue. 左值
  - Logical operators should return bool (or int for older compilers).

The prototypes of operators

- +-*/%^&|~
  - const T operatorX(const T& l, const T& r);
- ! && || < <= == >= >
  - bool operatorX(const T& l, const T& r);
- []　取元素
  - E& T::operator[](int index);

operators ++ and --

- How to distinguish postfix from prefix?
- postfix forms take an int argument -- compiler will pass in 0 as that int

```
class Integer {
public:
   ...
   const Integer& operator++();    //prefix++
   const Integer operator++(int); //postfix++
   const Integer& operator--();    //prefix--
   const Integer operator--(int); //postfix--
   ...
};
```

Operators ++ and --

加const，++a不能作为左值

```
const Integer& Integer::operator++() {
    *this += 1;          // increment
    return *this;        // fetch
}
```

+=也是重载

++在前，前缀

```
// int argument not used so leave unnamed so
// won't get compiler warnings
const Integer Integer::operator++( int ){
    Integer old( *this );    // fetch
    ++(*this);               // increment
    return old;              // return
}
```

调用了上面的operator

Using the overloaded ++ and --

```
// decrement operators similar to increment
    Integer x(5);
    ++x;
            // calls x.operator++();
    x++;
            // calls x.operator++(0);
    --x;
            // calls x.operator--();
    x--;
            // calls x.operator--(0);
```

- User-defined prefix is more efficient than postfix.

Relational operators

- implement != in terms of ==
- implement >, >=, <= in terms of <

用==来实现！=

```
class Integer {
      public:
          ...
      bool operator==( const Integer& rhs ) const;
      bool operator!=( const Integer& rhs ) const;
      bool operator<( const Integer& rhs ) const;
      bool operator>( const Integer& rhs ) const;
      bool operator<=( const Integer& rhs ) const;
      bool operator>=( const Integer& rhs ) const;
}
```

Relational operators

```
bool Integer::operator==( const Integer& rhs ) const {
   return i == rhs.i;
}
// implement lhs != rhs in terms of !(lhs == rhs)
bool Integer::operator!=( const Integer& rhs ) const {
   return !(*this == rhs);
}

bool Integer::operator<( const Integer& rhs ) const {
   return i < rhs.i;
}
```

Relational Operators...

```
// implement lhs > rhs in terms of lhs < rhs
bool Integer::operator>( const Integer& rhs ) const {
   return rhs < *this;
}
// implement lhs <= rhs in terms of !(rhs < lhs)
bool Integer::operator<=( const Integer& rhs ) const {
   return !(rhs < *this);
}
// implement lhs >= rhs in terms of !(lhs < rhs)
bool Integer::operator>=( const Integer& rhs ) const {
   return !(*this < rhs);
}
```

Operator []

- Must be a member function
- Single argument
- Implies that the object it is being called for acts like an array, so it should return a reference

```
Vector v(100);   // create a vector of size 100
v[10] = 45;
```

(Note: if returned a pointer you would need to do:

```
*v[10] = 45;
```

See: vector.h, vector.cpp