

Discussion of an example: an array of floating point numbers

P. Ronchese

Dipartimento di Fisica e Astronomia “G.Galilei”

Università di Padova

“Object oriented programming and C++” course

An example

Same details of an example will be discussed:
an array of floating point numbers with improved functionalities

- Dynamic memory handling
- Operator usage
- `const` functions/operators
- Copy constructor and assignment

Discussion

Some weakness of the first simple implementation
will be shown

- Crashes induced by unforeseen usage
- Analysis of the bug
- Solutions for the error

Constructor, destructor and data members

- Constructor: takes the size as argument
- Data members:
 - array size
 - pointer to array content

```
class FloatArray {  
public:  
    FloatArray(unsigned int n);  
    ~FloatArray();  
    ...  
private:  
    unsigned int eltn;  
    float* cont;  
};
```

Functions and operators

- A function to return the size
- Two operators to access content by index:
 - one `const` to be used with `const` arrays, returning a reference to `const float`,
 - one `non-const` to be used with `non-const` arrays.
 - the compiler takes care of calling the proper one

```
class FloatArray {  
public:  
    ...  
    unsigned int size() const;  
    const  
    float& operator[](unsigned int i) const;  
    float& operator[](unsigned int i);  
    ...  
};
```

Other elements

- An exception `class` to flag out-of-range access
- A function to check index
- A `static` flag to enable debugging

```
class FloatArray {  
    public:  
        ...  
    class OutOfRange {  
        public:  
            OutOfRange() {}  
            ~OutOfRange() {}  
    };  
    bool checkRange(unsigned int i) const;  
    static bool debug;  
    ...  
};
```

Memory allocation and deallocation

- The constructor takes care of memory allocation
- Destructor takes care of its deallocation

```
FloatArray::FloatArray(unsigned int n):  
    eltn(n),  
    cont(new float[eltn]) {  
    if(debug) cout << "created "  
                  << cont << endl;  
}  
FloatArray::~~FloatArray() {  
    if(debug) cout << "delete "  
                  << cont << endl;  
    delete[] cont;  
}
```

Size and range

- The array size is simply a number
- An index is in range if it's $0 \leq i < \text{eltn}$

```
unsigned int FloatArray::size() const {  
    return eltn;  
}  
  
bool FloatArray::checkRange(unsigned  
                             int i) const {  
    return (i < eltn);  
}
```


Access to content

- Access to content requires a prior check of index
- The array content are accessed by reference, so they can be modified (unless they're "const")

```
const
float& FloatArray::operator[](unsigned
                                int i) const {
    if(!checkRange(i))throw OutOfRange();
    return cont[i];
}
float& FloatArray::operator[](unsigned
                                int i) {
    if(!checkRange(i))throw OutOfRange();
    return cont[i];
}
```

Test program

A simple testing program can be easily written:
create a 5-element array and set them as 3.2 times their index

```
#include "FloatArray.h"
#include <iostream>
using namespace std;
int main() {
    unsigned int i;
    unsigned int n=5;
    FloatArray a(n);
    for(i=0;i<n;++i) a[i]=i*3.2;
    for(i=0;i<n;++i) cout << i << " "
                        << a[i] << endl;

    return 0;
}
```

Add a simple function

A simple function prints the array elements

```
void print(const FloatArray a) {  
    unsigned int i;  
    unsigned int n=a.size();  
    for(i=0;i<n;++i) cout << i << " "  
                        << a[i] << endl;  
    cout << "***" << endl;  
    return;  
}
```

Test the function

The function can be called just after the construction and setting of "a"

```
#include "FloatArray.h"
#include <iostream>
using namespace std;
int main() {
    unsigned int i;
    unsigned int n=5;
    FloatArray a(n);
    for(i=0;i<n;++i) a[i]=i*3.2;
    print(a); // print a
    for(i=0;i<n;++i) cout << i << " "
                        << a[i] << endl;

    return 0;
}
```

Crash in the execution

Trying to run, the program crashes!

```
void print(const FloatArray a) {  
    // "a" is passed by value:  
    // a local copy is done, containing  
    // a simple copy of "eltn" and "cont"  
    unsigned int i;  
    unsigned int n=a.size();  
    for(i=0;i<n;++i)cout << i << " "  
                        << a[i] << endl;  
    return; // when the copy of "a" is deleted  
}          // also "cont" is deleted,  
           // and "a" gets a dangling pointer
```

- Simple copy of a pointer: “shallow copy”
- Copy of data referred to by a pointer: “deep copy”

Robustness improvement

- Default object copy performs a “shallow copy”
- Object copies could be hidden
(mainly in function call and return)

Lowest-level protection: prevent object copying (in C++98/03)

```
class FloatArray {  
public:  
    ...  
private: // any "hidden" copy will be  
        // flagged by the compiler  
        // as an error  
    FloatArray(const FloatArray& a);  
    FloatArray& operator=(const FloatArray& a);  
    ...  
};
```

Implicit constructor & assignment suppression

Remove copy constructor and assignment: (since C++11)

Default constructors and/or operators may be removed

```
class FloatArray {  
public:  
    ...  
    // any "hidden" copy will be  
    // flagged by the compiler  
    // as an error  
    FloatArray(const FloatArray& a) = delete;  
    FloatArray& operator=(const FloatArray& a)  
        = delete;  
    ...  
};
```

Provide copy and assignment

- Object copies could be necessary
- Provide a copy constructor and assignment operator and make them public

```
class FloatArray {  
public:  
    ...  
    FloatArray(const FloatArray& a);  
    FloatArray& operator=(const FloatArray& a);  
    // object copying will be possible but  
    // the corresponding constructor and  
    // operator are to be provided  
private:  
    ...  
    void copy(const FloatArray& a);  
};
```


Deep copy

Deep copy can be “encapsulated” in a specific function

```
void FloatArray::copy(const FloatArray& a) {  
    if(cont==a.cont)return; // skip "a=a" cases  
    delete[] cont; // delete old content  
    cont=new float[eltn=a.eltn];  
    // copy size and allocate new memory  
    float* pr=a.cont+eltn; // copy elements  
    float* pl= cont+eltn; // one by one  
    while(pl>cont)*--pl=*--pr;  
    return;  
}
```

Implement constructor and assignment

The “copy” function can be used in constructor and assignment

```
FloatArray::FloatArray(const FloatArray& a):  
    cont(nullptr) { // set "cont" at nullptr so  
        copy(a); // that a "delete[]" has no effect  
    }  
FloatArray& FloatArray::operator=(  
    const FloatArray& a) {  
    copy(a);  
    return *this; // return the just-copied  
    }              // object as value
```

Temporary objects

Objects used in only one instruction

Some objects can be destroyed just after being created:

- returned by functions
- created only to be used as operands of function arguments

```
Pippo f();  
void g(Pippo p);  
  
...  
Pippo q = f();  
g(Pippo(...));  
g(f());  
...
```

Construction and assignment from temporary objects

C++11 only

Resources owned by temporary objects can be simply “moved” to avoid the cost of copying: “move” constructors and assignments taking a “rvalue reference” as argument.

```
class FloatArray {  
public:  
    ...  
    FloatArray(FloatArray&& a);  
    FloatArray& operator=(FloatArray&& a);  
    // construct or assign  
    // from temporary objects  
private:  
    ...  
    void move(FloatArray& a);  
};
```

Resource transportation

Resource move can be “encapsulated” in a specific function

```
void FloatArray::move(FloatArray& a) {  
    if(cont==a.cont)return; // skip "a=a" cases  
    delete[] cont; // delete old content  
    // copy pointer and size  
    cont=a.cont;  
    eltn=a.eltn;  
    // reset pointer and size in source object  
    a.eltn=0;  
    a.cont=nullptr;  
    return;  
}
```

Implement move constructor and assignment (C++11 only)

The “move” function can be used in constructor and assignment

```
FloatArray::FloatArray(FloatArray&& a):  
    cont(nullptr) { // set "cont" at nullptr  
                    // so that a "delete[]" has  
    move(a);        // no effect  
}  
FloatArray& FloatArray::operator=(  
    FloatArray&& a) {  
    move(a);  
    return *this; // return the just-moved  
}                // object as value
```

Summary

Recommendation

- Object copies could hide inside an apparently simple program
- Default copy is often unreliable, mainly when objects contain pointers
- Unless an object is very simple (only native variables, no pointers), add protection
 - Declare (at least) copy constructor and assignment operator as `private` (or `deleted` in C++11)
 - Provide, if needed, an explicit implementation of them
 - “The rule of 3”: if any one among destructor, copy constructor and assignment operator is defined, then all the 3 should be defined as well
- C++11 allows transferring the resources from temporary objects (move constructor and assignment): “rule of 5”

Appendix: RVO

Return Value Optimization

When possible, the compiler may generate code to avoid copying (or moving) of objects: temporary objects are elided in the creation or assignment of objects in the client.

BEWARE: side effects in constructor/destructor may be difficult to control!