

## Mopping Up

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- static and global – scoping rules
- pointers to functions, void\*
- inline
- recursion
- other types: String, enum
- nested classes
- typedef, struct
- multiple inheritance; “is a” and “has a”; container classes
- exceptions

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## Introduction

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- To finish off, we look at many of the “small” rules that are useful, important, or simply annoying, but didn’t merit their own section.
- I won’t be “inclusive” – there will be several small details I will leave as “exercises for the student”
- See other books, ANSI standard, etc.

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## static and global – scoping rules

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- So far, variables have been
  - class member data
  - local variables of limited scope – within {}
- If the variable goes out of scope, or the object goes out of scope, the variable is gone.
- To prevent this, we can declare a variable `static`.
- when part of a class, it becomes a *class variable*, rather than an *instance variable*.

Let’s look at an example:

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```
#ifndef __FLOAT_HH // Float1.hh
#define __FLOAT_HH
#include <iostream.h>

class Float {
public:
    Float(float x=0.0);
    float operator()() const;
    friend ostream& operator<<(ostream&, const Float&);
private:
    float m_x;
    static unsigned long m_get;
};

#endif // __FLOAT_HH
```

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This is a class that encapsulates a `float`, and uses a `static` to keep track of how many times the field is accessed.

```
#include "Float1.hh" // Float1.cc

Float::Float(float x) : m_x(x) {}

float Float::operator()() const { m_get++; return m_x; }

unsigned long Float::m_get();

ostream& operator<<(ostream& os, const Float& f) {
    os << f.m_x << " (field accessed " << Float::m_get << " times)";
    return os;
}
```

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```
#include "Float1.hh" // Static1.cc

int main() {
    const Float a(3.14159);
    Float b(2.7);
    float x(0.0);
    for (int i=0; i<10; i++) {
        x += a() + b();
    }
    cout << "a=" << a << endl;
    a.~Float();
    Float c(1.414);
    cout << "x = " << x+c() << endl;
    cout << "c=" << c << endl;
    return 0;
}
```

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Points to note:

- We overload `operator()()`, the function call operator, to provide a “natural” accessor function. Note that we must declare it `const`.
- The variable `m_get` is declared `static`. It is initialized in `Float.cc`
- In `ostream& operator<<()`, we refer to `f.m_x` (since it is for that particular object), but `Float::m_get` (since it is for the whole class).
- We explicitly call the destructor for `a`, to ensure that `a` is out of scope.
- Since `Float::m_get` is static, it exists without an object instance.

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- What if we need to *access* static members?
- – if the member is `const` we can make it `public`  
(This is the exception to making all data members private)
  - otherwise, we must use a *static function*  
It has to be static to allow access without an object
- Using static class members almost completely removes the need for global data - with a bonus:

The class name removes global naming ambiguities

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```
#ifndef __FLOAT_HH // Float2.hh
#define __FLOAT_HH
#include <iostream.h>

class Float {
public:
    Float(float x=0.0);
    float operator()() const;
    friend ostream& operator<<(ostream&, const Float&);
    static unsigned long getStatic() { return m_get; }
    static const float PI;
private:
    float m_x;
    static unsigned long m_get;
};

#endif // __FLOAT_HH
```

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```
#include "Float2.hh" // Float2.cc

Float::Float(float x) : m_x(x) {}

float Float::operator()() const { m_get++; return m_x; }

unsigned long Float::m_get(0);
const float Float::PI(3.14159);

ostream& operator<<(ostream& os, const Float& f) {
    os << f.m_x << " (field accessed " << Float::m_get << " times)";
    return os;
}
```

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```
#include "Float2.hh" // Static2.cc

int main() {
    const Float a(1.414);
    Float b(2.7);
    float x = a() + b() + Float::PI;
    cout << "x = " << x << endl;
    cout << "field accessed: " << Float::getStatic() << endl;
    return 0;
}
```

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## File and Global Scope

- Sometimes, we have to make the scope of an object the whole file, or even the whole program.
- We can make an object `static` or `extern`



In C++ `extern` should be almost completely avoided. It can break encapsulation, and there are other, better ways

As an example, consider a program with 3 parts:

- Initialization
- A main loop
- Termination

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```
#ifndef __JOB_HH // Job.hh
#define __JOB_HH
#include <iostream.h>

class Job {
public:
    static Job* Instance();
    void begin();
    void middle();
    void end();
private:
    Job();
    static Job* m_instance;
};

#endif // __JOB_HH
```

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This is a useful class that guarantees only one instance of an object.  
It is called a **Singleton** class.

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```
#include "Job.hh" // Job.cc

Job* Job::m_instance(0);

Job* Job::Instance() {
    if (m_instance == 0) {
        m_instance = new Job();
    }
    return m_instance;
}

Job::Job() {}
```

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First put all the functions in one file:

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```
#include "Job.hh" // Driver1.cc

static int global;

void Job::begin() { cout << "begin: global=" << (global=0)<<endl; }
void Job::middle() { cout << "middle: global=" << ++global << endl; }
void Job::end() { cout << "end: global=" << global << endl; }

int main() {
    Job* j=Job::Instance();
    j->begin();
    for (int i=0; i<10; i++) j->middle();
    j->end();
    return 0;
}
```

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Then put the “driver” program and each function in separate files:

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```
#include "Job.hh" // Driver2.cc

int main() {
    Job* j=Job::Instance();
    j->begin();
    for (int i=0; i<10; i++) { j->middle(); }
    j->end();
    return 0;
}
```

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The global object (`global`) has to be defined once and once only, but declared `extern` wherever it is used.

```
#include "Job.hh" // Job_begin.cc

int global(0); // more usually would be an object

void Job::begin() {
    extern int global;
    cout << "begin: global=" << global << endl;
}
```

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Points to note:

- We define a `Job` class that can only have one instance. We do this with:
  - a static private pointer to the instance
  - a private constructor
  - a public static function, `Instance`
- In `main`, we create a singleton `Job` instance, and call `begin`, `middle`, `end` as user-supplied member functions.
- `global` is declared and defined `static int` – it can then be used by all 3 functions.
- In the second case, the file containing `main` doesn't know about `global`, nor the function implementations
- Then `global` has to be *declared* `extern` wherever it is used, and *defined* exactly once.

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## pointers to functions, `void*`

- A function has an address – its code is somewhere in memory.
- We can use that address to pass a function name to another function.
- Using virtual functions, we don't have to do this very often

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```
#include <iostream.h> // Dispatcher2.cc

void f1(const int* p) { cout << "I am f1 " << *p << endl; }

void f2(const float* p) { cout << "I am f2 " << *p << endl; }

void dispatcher(void (*f)(const void*), const void* p) { (*f)(p); }

int main() {
    const int* i = new int(17);
    const float* x = new float(3.14159);
    dispatcher(f1, i);
    dispatcher(f2, x);
    return 0;
}
```

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Points to note:

- The syntax gets messy (see K&R).
  - `void (*f)` is a *pointer* to a function which is `void`. This is *not* the same as:
    - `void* f` – which is a function that returns a `void*`
- In the prototype, we have to specify the number and types of arguments
- We use the special pointer `void*`, to mean “this is a pointer, but we don’t know what type”. *Eventually* we have to know the type (in function `f1` and `f2`)
- Any pointer can be cast to `void*`

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## inline

- The `inline` keyword allows a function to be expanded “inline”.
- The use of `inline` makes macros almost redundant (which is why I didn’t tell you about them).
- A function which is *defined* with its class *declaration* is automatically inline.
- The definition must be in the header file (or where the code is used – how else could it be inlined?)
- Access functions are often inlined.



Use `inline` sparingly. Look at the performance *first* before deciding to inline a function.

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```
#ifndef __POINT_HH // Point1.hh
#define __POINT_HH
#include <math.h>
#include <iostream.h>

class Point {
public:
    Point(int initX=0, int initY=0);
    int x() { return m_x; } // this will be inlined
    int y() { return m_y; } // this will be inlined
    inline int r(); // as too will this
    friend ostream& operator<<(ostream& os, const Point&);

private:
    int m_x, m_y;
};

int Point::r() {
    return (int)sqrt( m_x*m_x + m_y*m_y );
}

#endif // __POINT_HH
```

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The calling code is the same – it doesn’t know whether or not a member function is `inline`.

```
#include "Point1.hh" // Inline.cc

int main() {
    Point* p = new Point(3,4);
    cout <<"Point: "<< *p <<, r="<< p->r() << endl;
    return 0;
}
```

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## recursion

- C++ supports recursion – calling function `foo` from inside `foo`.
- All recursive functions must have a termination condition.



Recursion should be used carefully.  
Sometimes it is very efficient. Sometimes  
it is very inefficient.

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```
#include <iostream.h> // factorial.cc
#include <assert.h>

double factorial(int n) {
    assert(n>=0);
    if (n<=1) return 1.0;
    else return n*factorial(n-1);
}

int main() {
    for (int i=0; i<100; i++) {
        cout << i << "!" = " " << factorial(i) << endl;
    }
    return 0;
}
```

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## other types: String

- We've already met the `String` class – declared in `String.h`
- In C, strings are represented by an array of `char`. `class String` is just an encapsulation of `char*` – with some member functions.
- Since `String` is fairly recent, you will see both `String` and `char*`.
- Member functions: look in `String.h`  
*Note:* `String.h` makes the old `string.h` almost redundant.



class String contains a pointer to a  
`char*`, so be careful when making classes  
containing String persistent.

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## other types: enum

- C++ supports an *enumeration* type, `enum` – a type that allows only certain integer values.
- It is often used in a way similar to `static` to define constant values for a class.
- It is a type in its own right – `int` cannot be cast to `enum` (but vice versa is OK).
- It can be used with, or without, declaring an `enum` type.

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```

#ifndef __FONTSIZE_HH // FontSize.hh
#define __FONTSIZE_HH

class FontSize {
public:
    enum { TINY, SMALL, NORMAL, LARGE, HUGE };
};

#endif // __FONTSIZE_HH



---


#include <iostream.h> // FontSize.cc
#include "FontSize.hh"

int main() {
    cout << FontSize::SMALL << endl;
    return 0;
}

```

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```

#ifndef __PIXEL_HH // Pixel.hh
#define __PIXEL_HH
#include <iostream.h>
#include "Point1.hh"

class Pixel : public Point {
public:
    enum Color { BLACK, WHITE, RED, GREEN, BLUE };
    Pixel(int initX=0, int initY=0, Color initColor=BLACK);
    friend ostream& operator<<(ostream& os, const Pixel&);

private:
    Color m_color;
};

#endif // __PIXEL_HH

```

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```

#include "Pixel.hh" // Pixel.cc

Pixel::Pixel(int initX, int initY, Color initColor)
: m_color(initColor), Point(initX, initY) {}

ostream& operator << (ostream& os, const Pixel& p) {
    os << (Point)p << ", color=" << p.m_color;
    return os;
}

```

Note:

- the use of the type `Color`
- the cast to `Point` for the `<<` argument

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```

#include "Pixel.hh" // Enum.cc

int main() {
    const kPixels(3);
    Pixel* p[kPixels];
    p[0] = new Pixel(3,4, Pixel::RED);
    p[1] = new Pixel(6,7, Pixel::GREEN);
    p[2] = new Pixel(5,9, Pixel::BLUE);
    for (int i=0; i<kPixels; cout<<*p[i]<<endl ) {}
    return 0;
}

```

Note the use of an array of pointers to an object (deferring calling the constructor).

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## nested classes

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- A class can be defined inside the scope of another class. This is a *nested* class.
- The access rules are the same as for any other member object:
  - the class can be `public` or `private`
  - the scope resolution operator, `::` is needed outside the class.
- This is useful if the nested class only has meaning in the context of the outer class.

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```
class Outer {  
public:  
    ...  
    class Inner {  
public:  
    Inner();  
    ...  
private:  
    ...  
};  
private:  
    ...  
};
```

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```
#include "Nested.hh" // Nested.cc  
  
int main() {  
    Outer a;  
    Outer::Inner b(2.7);  
    cout << "Outer = " << a << endl;  
    cout << "Outer::Inner = " << b << endl;  
    return 0;  
}
```

- 
- Since class `Inner` is a member of class `Outer`, we have to refer to it as `Outer::Inner`
  - The previous `enum` example is really a nested class

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## typedef

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- A `typedef` allows us to define a new type in terms of an old one.
- Syntax: `typedef float Float`  
makes the new type `Float` a synonym for `float`
- We can use more complicated declarations:  
`typedef Stack<int> intStack`
- In C, `typedef` was as good as could be done. In C++, we need it far less. They are most often encountered in standard header files.

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## struct

- Another hangover from C. In C, a *struct* was like a class with only public data members.
- In C++, a *struct* is *almost* like a *class* *except* that the default access is *public*.
- Unlike in C, a *struct* can also have member functions, inheritance, etc.



Don't use *struct* in C++. Always use *class*.

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## multiple inheritance

- C++ supports multiple inheritance (Java does not). A derived class inherits the members of *multiple* base classes.



Other things being equal, multiple inheritance should generally be avoided.

- The inheritance family tree can get very knotted.
- Data and functions of independent base classes can interfere
- Often, it's not inheritance we need at all

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```
#include <iostream.h> // Multiple.hh

class Base1 {
public:
    Base1(int initX1) { m_x1=initX1; }
    int x1() const { return m_x1; }
private:
    int m_x1;
};

class Base2 {
public:
    Base2(float initX2) { m_x2=initX2; }
    float x2() const { return m_x2; }
private:
    float m_x2;
};
```

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```
#include "Multiple.hh" // Multiple.cc

class Derived : public Base1, public Base2 {
public:
    Derived(int initX1=0, float initX2=0.0f)
        : Base1(initX1), Base2(initX2) {}
    friend ostream& operator<<(ostream&, const Derived&);
};

ostream& operator<<(ostream& os, const Derived& d) {
    os << "(" << d.x1() << "," << d.x2() << ")";
    return os;
}

int main() {
    Derived a(42, 3.14159);
    cout << "a = " << a << endl;
    return 0;
}
```

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## “is a” and “has a”

The “litmus test” for whether to use inheritance is the “is a” vs. “has a” test.

- If an object of class **A** *is* an object of class **B**, then use inheritance.
- If an object of class **A** *has* an object of class **B**, then use a container class.

Unfortunately, like all definitive tests, this one isn’t. But it’s a good start.

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```
#ifndef __HOUSE_HH // House.hh
#define __HOUSE_HH
#include <iostream.h>
#include <String.h>
class Room;
class House {
public:
    House(const String& name) : m_name(name), m_n(0), m_rooms(0) {}
    void addRoom(const Room&);
    ~House();
    friend ostream& operator<<(ostream&, const House&);
private:
    String m_name;
    int m_n;
    Room* m_rooms;
    House(const House&); // don't allow copy constructor
    void operator=(const House&); // nor assignment operator
};

#endif // __HOUSE_HH
```

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## container classes

Another version of the same test is:

- Could an object of class **A** have several objects of class **B**?

If so, then we almost certainly don’t want to use inheritance, but rather a container class.

- A container class simply “contains” objects of other classes. The objects could be:
  - the objects themselves
  - pointers to the objects. Sometimes, it’s useful to make a “wrapper” class for the pointer.

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```
#ifndef __ROOM_HH // Room.hh
#define __ROOM_HH
#include <iostream.h>
#include <String.h>

class Room {
public:
    Room() {}
    Room(const String& name, float l=0.0f, float w=0.0f)
        : m_name(name), m_l(l), m_w(w) {}
    Room& operator=(const Room&);
    ~Room() {}
    float area() const { return m_l*m_w; }
    friend ostream& operator<<(ostream&, const Room&);

private:
    String m_name;
    float m_l;
    float m_w;
};

#endif // __ROOM_HH
```

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```

#include "House.hh"    // House-Room.cc
#include "Room.hh"

int main() {
    House h("123 Any Street, Newtown");
    h.addRoom(Room("Living", 25, 20));
    h.addRoom(Room("Bedroom #1", 20, 17));
    h.addRoom(Room("Bedroom #2", 16, 12));
    h.addRoom(Room("Bedroom #3", 12, 8));
    h.addRoom(Room("Kitchen", 16, 13));
    cout << h << endl;
}

```

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Points to note:

- the forward declaration of class `Room`.
- class `House` contains an array of rooms
- The copy constructor and `operator=( )` are declared `private`, but not defined. This prevents their inadvertent use.
- We need a destructor (since we'll be dynamically allocating memory).
- class `Room` is the contained object. If it dynamically allocated memory, we'd need copy constructors, etc.
- We explicitly define the default constructor (for use by `new`).
- We add objects to `House` with:  
`h.addRoom(Room("Living", 25, 20));`  
 (that's where the work is, but you know how to do that.)

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## wrapper classes

- A “bare” pointer can be dangerous, for all the usual reasons
- It’s often good to protect ourselves (this will be done repeatedly in STL) by “wrapping” the pointer in a class.
- By ensuring that this wrapper class has the usual army of:
  - copy constructor
  - default constructor
  - destructor
  - assignment operator
 we can make it “container safe”.
- The `String` class is such a class. We’ll do similar with class `Wrapper`.

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```

#ifndef __WRAPPER_HH    // Wrapper.hh
#define __WRAPPER_HH
#include <iostream.h>
class Foo {
public:
    int m_size;  char* m_array;
};

class Wrapper {
public:
    Wrapper();
    Wrapper(char*);
    Wrapper(const Wrapper&);
    Wrapper& operator=(const Wrapper&);
    virtual ~Wrapper();
    friend ostream& operator<<(ostream&, const Wrapper&);

private:
    Foo* rep;
};

#endif // __WRAPPER_HH

```

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```

#ifndef __ROOM_HH // Room2.hh
#define __ROOM_HH
#include "Wrapper.hh"

class Room {
public:
    Room() {}
    Room(const Wrapper& name, float l=0.0f, float w=0.0f)
        : m_name(name), m_l(l), m_w(w) {cout<<"Room constructor"<<endl;}
    ~Room() {}
    Room(const Room&);
    float area() const { return m_l*m_w; }
    friend ostream& operator<<(ostream&, const Room&);
private:
    Wrapper m_name;
    float m_l;  float m_w;
};
ostream& operator<<(ostream& os, const Room& r) {
    os<<r.m_name<<, L=<<r.m_l<<, W=<<r.m_w<<, area=<<r.area();
    return os;
}

```

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Points to note:

- The only data in class `Wrapper` is a pointer to `Foo`
- The data in `Foo` are public, but `Wrapper`'s instance (`rep`) is still private.
- `Wrapper` has the usual army of constructors, destructor, etc.
- We put print statements in `Wrapper`'s constructors, etc. to make it clear what's happening.
- Because the pointer is "wrapped", class `Room` can use the default constructors, etc. It thinks `Wrapper` is a "regular" class.
- We exercise the class with objects being created, deleted, going out of scope.

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```

#include "Room2.hh" // Room-Wrapper.cc

int main() {
    Room* a = new Room("room 1", 23, 17);
    cout << *a << " -----" << endl;
    Room b=a;
    delete a;
    cout << b << " -----" << endl;
    for (int i=0; i<1; i++) {
        Room c("room", 12*(i+1), 8*(i+1));
        cout << c << " -----" << endl;
    }
    Room d(b);
    cout << d << " -----" << endl;
}

```

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```

Wrapper::Wrapper(char* s)
Wrapper::Wrapper(const Wrapper& w)
Room constructor
Wrapper::~Wrapper()
room 1, length=23, width=17, area=391 -----
Wrapper::Wrapper(const Wrapper& w)
Wrapper::~Wrapper()
room 1, length=23, width=17, area=391 -----
Wrapper::Wrapper(char* s)
Wrapper::Wrapper(const Wrapper& w)
Room constructor
Wrapper::~Wrapper()
room, length=12, width=8, area=96 -----
Wrapper::~Wrapper()
Wrapper::Wrapper(const Wrapper& w)
room 1, length=23, width=17, area=391 -----
Wrapper::~Wrapper()
Wrapper::~Wrapper()

```

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## exceptions

- The idea behind exceptions is:
  - A *function* knows best how to *detect* an error.
  - The *calling* program knows best how to *handle* the error.
- We could simply call `exit`, or use `assert`, but that's often too drastic.
- Conventionally, we second guess all possible errors and *avoid* them.  
We usually can't anticipate *all* errors
- Instead, an *Exception Handler* lets the function detect the error, and the calling program handle it. This is what we want.

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### Syntax:

1. The function is called inside a `try` block.
2. If the function detects an error, it `throws` an object.
3. This object is caught by the calling program inside a `catch` block.
4. There can be multiple `catch` blocks – each catching a different object.

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Exceptions break the normal program flow control:

1. If no exception was thrown:
  - the function exits normally
  - the whole `try` block is executed
  - none of the `catch` block is executed
2. If an exception was thrown:
  - the function exits at the `throw` statement
  - the rest of the `try` block is skipped
  - the relevant `catch` block is executed

In both cases, control resumes after the last `catch`.

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```
#include <iostream.h> // Exception1.cc
#include <math.h>

double mySqrt(double x) {
    if ( x<0 ) { throw "argument must be >= 0"; }
    return sqrt(x);
}

int main() {
    double x;
    while (1) {
        cout << "Enter a number: " << endl;
        if ( !(cin>>x) ) { cout << endl; break; }
        try {
            cout << "sqrt(" << x << ") = " << mySqrt(x) << endl;
        } catch(char* message) { cout << message << endl; }
    }
    return 0;
}
```

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Points to note:

- To enable exceptions with `g++`, we have to use the flag:  
`g++ -Wall -fhandle-exceptions`
- The exception object is a `char*` – which is a built-in type.
- More generally, the `throw` is calling the constructor for the thrown object.
- The `catch` looks just like a function, with the thrown object as its argument.

And now for a more complicated example:

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```
#ifndef __EXCEPTIONARRAY_HH
#define __EXCEPTIONARRAY_HH
#include "Exceptions.hh"

template <class T>
class ExceptionArray {
public:
    ExceptionArray(int);
    virtual ~ExceptionArray();
    T& operator[](int);
private:
    int m_size;
    T* m_array;
    ExceptionArray(const ExceptionArray&); // disable
    ExceptionArray& operator=(const ExceptionArray&); // disable
};

template <class T>
ExceptionArray<T>::ExceptionArray(int size) : m_size(size){
    if (size<0) { throw ArraySizeError(size); }
    m_array = new T[m_size];
    if (m_array==0) { throw AllocateError(); }
}

template <class T>
ExceptionArray<T>::~ExceptionArray() { delete [] m_array; }

template <class T>
ExceptionArray<T>::operator[](int i) {
    if ( (i<0) || (i>m_size) ) { throw SubscriptError(i); }
    return m_array[i];
}
#endif // __EXCEPTIONARRAY_HH
```

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```
class ArraySizeError { // Exceptions.hh
public:
    ArraySizeError(int size) : m_size(size) {}
    int badArraySize() { return m_size; }
private:
    int m_size;
};
class AllocateError {
public:
    AllocateError() {}
    int badAllocate() { return -1; }
};
class SubscriptError {
public:
    SubscriptError(int i) : m_i(i) {}
    int badArraySubscript() { return m_i; }
private:
    int m_i;
};
```

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```
#include <iostream.h> // ExceptionArray-Throw.cc
#include "ExceptionArray.hh"
main() {
    try {
        ExceptionArray<int> a(-7);
        cout << "we shouldn't get here" << endl;
    } catch(ArraySizeError e) {
        cout << "caught ArraySizeError: " << e.badArraySize() << endl;
    }
    try {
        ExceptionArray<int> b(6);
        cout << "b[13] = " << b[13] << endl;
    } catch(ArraySizeError e) {
        cout << "caught ArraySizeError: " << e.badArraySize() << endl;
    } catch(SubscriptError e) {
        cout << "caught SubscriptError: " << e.badArraySubscript() << endl;
    } catch(AllocateError e) {
        cout << "caught AllocateError: " << e.badAllocate() << endl;
    }
}
```

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