

# Modern C++ Programming

## 11. ADVANCED TOPICS

---

*Federico Busato*

University of Verona, Dept. of Computer Science  
2018, v1.0



# Agenda

## ▪ Move Semantic

- lvalues and rvalues
- Class move semantic
- `std::move`
- Universal reference
- Reference collapsing rules
- Type deduction
- Copy elision and RVO
- Perfect forwarding
- Compiler implicitly declared

## ▪ C++ Idioms

- Rules of Three (and Zero)
- Rules of Five
- Singleton
- PIMLP
- CRTP
- Template virtual function

## ▪ Smart Pointers

- `std::unique_ptr`
- `std::shared_ptr`
- `std::weak_ptr`

## ▪ Concurrency

- Thread methods
- Parameters passing
- Mutex
- Atomic
- Task-based parallelism

## ▪ C++ Guidelines

# Move Semantic

---

# Overview

*Move semantics is about transferring ownership of resources from one object to another*

It is different from **copy semantic** which give you a duplicate of the original resource

In C++ every expression is either an **rvalue** or an **lvalue**

- a **lvalue** represents an object that occupies some identifiable location in memory
- a **rvalue** is an expression that does not represent an object occupying some identifiable location in memory

```
int x = 5; // x is a lvalues
```

```
int y = 10; // y is a lvalues
```

```
int z = (x * y); // y is an lvalue, (x * y) is an rvalue
```

C++11 introduces a new kind of reference called **rvalue** reference

`X&&`

- An **rvalue** reference only binds to an rvalue, that is a temporary
- A **lvalue** reference binds to an lvalue, or to an rvalue if the lvalue reference is `const`

```
int main() {  
    int      x = 5; // x is a lvalues  
    const int& y = 10; // y is a lvalues reference  
  
    const int& z = (x * y); // z is a lvalue const reference  
                          // to an rvalue  
  
    int&&      rv1 = (x * y);  
    // int&&    rv2 = x; // x is not an rvalue  
}
```

```
struct A {};  
  
void f(A& a) {}  
  
void g(const A& a) {}  
  
void h(A&& a) {}  
  
int main() {  
    A a;  
    f(a); // ok, f() can modify "a"  
    g(a); // ok, f() cannot modify "a"  
    // h(a); // compile error!! f() does not accept rvalues  
  
    // f(A()); // compile error!! f() does not accept rvalues  
    g(A()); // ok, f() cannot modify the object A()  
    h(A()); // ok, f() can modify the object A()  
}
```

## The problem:

```
#include <algorithm>
#include <iostream>
struct AW { // array wrapper
    int _size;
    int* _array;

    AW(int size) : _size(size) {
        array = new int[size];
    }
    AW(const AW& obj) : _size(obj._size){
        std::cout << "copy";
        _array = new int[_size];
        std::copy(obj._array,
                  obj._array + _size,
                  _array);
    }
    ~AW() {
        delete[] _array;
    }
};
```

```
#include <vector>

int main() {
    std::vector<AW> vector;
    vector.push_back( AW(10) );
    // use vector
}
```

AW(10) cannot be passed by reference, otherwise `_array` is deallocated and it is no more valid in `vector`

Pass-by-value forces using the copy constructor, but it performs redundant operations (constructor + copy) since `AW(10)` is not more needed in `main`

Class prototype with support for move semantic:

```
class X {  
public:  
    X();           // default constructor  
  
    X(const X& obj); // copy constructor  
  
    X(X&& obj);    // move constructor  
  
    X& operator=(const X& obj); // copy assign operator  
  
    X& operator=(X&& obj);     // move assign operator  
  
    ~X();           // destructor  
private:  
    Y _data;  
};
```



```
X(X&& obj);
```

## Move constructor semantic:

- (1) Shallow copy of `obj` data members (in contrast to deep copy)
- (2) Release any `obj` resources and reset all data members (pointer to `nullptr`, size to 0, etc.)

```
X& operator=(X&& obj);
```

## Move assignment semantic:

- (1) Release any resources of `this`
- (2) Shallow copy of `obj` data members (in contrast to deep copy)
- (3) Release any `obj` resources and reset all data members (pointer to `nullptr`, size to 0, etc.)
- (4) Return `*this`

```
AW(AW&& obj) {  
    _size = obj._size;    // (1) shallow copy  
    _array = obj._array; // note the difference with the copy constructor  
    obj._size = 0;       // (2) release obj (it is not more valid)  
    obj._array = nullptr; // obj has been moved to *this  
}
```

```
AW& operator=(AW&& obj) {  
    delete[] _array;    // (1) release this  
    _size = obj._size; // (2) shallow copy  
    _array = obj._array;  
    delete[] obj._array; // (3) release obj  
    obj._size = 0;  
    return *this;      // (4) return *this  
}
```

**C++11** provides the method `std::move` ( `<utility>` ) to indicate that an object may be “moved from”

It allows to efficient transfer resources from an object to another one

Considering the class array wrapper `AW` with support for move semantic:

```
#include <vector>

int main() {
    std::vector<AW> vector;
    vector.push_back( AW(10) ); // call move constructor
    // use vector

    AW aw(10);
    vector.push_back( aw );      // call copy constructor

    vector.push_back( std::move(aw) ); // call move constructor
}
```

# Universal Reference

The `&&` syntax has two different meanings depending on the context it is used

- `rvalue` reference
- Either `rvalue` reference or `lvalue` reference  
(*universal reference*, cit. Scott Meyers)

```
struct A {};  
  
void f(A&& a) {} // rvalue only  
  
template<typename T>  
void g(T&& t) {} // universal reference  
  
int main() {  
    A a;  
    f(A()); // ok  
    // f(a); // compile error (only rvalue)  
    g(A()); // ok  
    g(a);   // ok  
}
```

```
void h() {  
    A a1;  
    A&& a2 = A(); // ok  
    // A&& a3 = a1; // compile error  
    // (only rvalue)  
  
    auto&& a4 = A(); // ok  
    auto&& a5 = a1;  // ok  
  
    A&& a6 = std::move(a1); // ok
```

## Reference Collapsing Rules

Before C++11 (C++98, C++03), it was not allowed to take a reference to a reference ( `A&&` causes a compile error)

C++11, by contrast, introduces the following **reference collapsing rules**:

```
template<typename T>
void f(T& a) {} // compile error in C++98/03
int main() { // (with gcc), no errors in C++11
    int a = 3; // (and clang with C++98/03)
    f<int&>(a);
}
```

| Type | Reference |   | Result |
|------|-----------|---|--------|
| A&   | &         | → | A&     |
| A&   | &&        | → | A&     |
| A&&  | &         | → | A&     |
| A&&  | &&        | → | A&&    |

# Type Deduction (Template)

| Type       | T        | T&            | const T&      | T&&              |
|------------|----------|---------------|---------------|------------------|
| A a        | A        | A&            | const A&      | A& &&            |
| A&         | A        | A&            | const A&      | A& &&            |
| const A&   | A        | const A&      | const A&      | const A& &&      |
| A&&        | A        | const A&      | const A&      | A& &&            |
| A*         | A*       | A*&           | const A*&     | A*& &&           |
| const A*   | const A* | const A*&     | const A*&     | const A*& &&     |
| A[3]       | A*       | (A&)[3]       | const (A&)[3] | (A&)[3] &&       |
| const A[3] | const A* | const (A&)[3] | const (A&)[3] | const (A&)[3] && |

# Type Deduction (auto)

---

| Type      | auto     | auto&         | const auto&   | auto&&        |
|-----------|----------|---------------|---------------|---------------|
| A a       | A        | A&            | const A&      | A&            |
| A&        | A        | A&            | const A&      | A&            |
| const A&  | A        | const A&      | const A&      | const A&      |
| A&&       | A        | A&            | const A&      | A&            |
| A*        | A*       | A*&           | const A*&     | A*&           |
| const A*  | const A* | const A*&     | const A*&     | const A*&     |
| A[3]      | A*       | (A&)[3]       | const (A&)[3] | (A&)[3]       |
| const A[] | const A* | const (A&)[3] | const (A&)[3] | const (A&)[3] |

---

# Type Deduction (std::initializer\_list)

```
#include <utility>
template<typename T>
void f(T a) {}

template<typename T>
void g(std::initializer_list<int>) {}

// auto h1() { return { 1, 2, 3 }; } // compile error

auto h2() { // ok
    return std::initializer_list<int>({ 1, 2, 3 });
}

int main() {
    auto x = { 1, 2, 3 }; // x: std::initializer_list<int>
    // f( { 1, 2, 3 } ); // compile error
    g( { 1, 2, 3 } ); // ok
}
```



# Type Deduction (decltype)

decltype can be combined with auto to prevent *type decay*

```
struct A {};  
  
auto g() {           // auto : A  
    A a;  A& a1 = a;  
    return a1;  
}  
decltype(auto) g() { // decltype(auto) : A& !!  
    A a;  A& a1 = a;  
    return a1;  
}  
decltype(auto) g() { // decltype(auto) : A& !!  
    A a;  
    return (a); // without ( expr ) decltype(auto) : A  
}  
int main() {  
    A a;  
    const A& a1 = a;  
    auto      x = a1; // x is of type "A"  
    decltype(auto) y = a1; // y is of type "const A&"  
}
```

**Copy elision** is a compiler optimization technique that eliminates unnecessary copying/moving of objects (it is defined in the C++ standard)

A compiler avoids omitting copy/move operations in these cases:

- **RVO (Return Value Optimization)** means the compiler is allowed to avoid creating *temporary* objects for return values
- **NRVO (Named Return Value Optimization)** means the compiler is allowed to return an object (with automatic storage duration) without invokes copy/move constructors

```
AW f1() {
    return AW(10); // RVO
}

AW f2() {
    AW aw(10);
    return aw; // NRVO
}

AW f5() {
    AW aw(10);
    return std::move(aw);
} // move constructor

AW f3(bool b) {
    return b ? AW(10) : AW(5); // RVO
}

AW f4(bool b) {
    AW aw1(10), aw1(5);
    return b ? aw1(10) : aw1(5);
} // copy constructor
```

```
AW&& f6() {
    return AW(10);
    std::move(aw); // RVO
}

AW aw_global(10);

AW&& f7() {
    return aw_global;
} // copy constructor

struct B {
    AW aw(10);
} b;

AW f8() {
    return b.aw; // copy constructor
}

int main() {
    AW aw = f1(); // ok RVO
    aw = f1();
} // move operator= (no RVO)
```

# Perfect Forwarding

`std::forward` ( `<utility>` ) forwards the argument to another function with the value category it had (lvalue/rvalue and const/volatile modifiers) when passed to the calling function (*perfect forwarding*)

```
#include <iostream>
template<typename T>
void g(T& t) {
    std::cout << "lvalue";
} // g(T&) is never called if g(A(10))
```

```
template<typename T>
void g(T&& t) {
    std::cout << "rvalue";
}
```

```
// template<typename T>
// void g(T t) {
//     when call f1() T cannot
//     deduce T& or T&&
```

```
template<typename T>
void f1(T&& obj) {
    g( obj );
}

template<typename T>
void f2(T&& obj) {
    g( std::forward<T>(obj) );
}
```

```
int main(int argc) {
    g ( A(10) ); // print "rvalue"
    f1( A(10) ); // print "lvalue"!!
    f2( A(10) ); // print "rvalue" 18/54
}
```

## Special Members

compiler implicitly declares

|                     | default constructor | destructor    | copy constructor | copy assignment | move constructor | move assignment |
|---------------------|---------------------|---------------|------------------|-----------------|------------------|-----------------|
| Nothing             | defaulted           | defaulted     | defaulted        | defaulted       | defaulted        | defaulted       |
| Any constructor     | not declared        | defaulted     | defaulted        | defaulted       | defaulted        | defaulted       |
| default constructor | user declared       | defaulted     | defaulted        | defaulted       | defaulted        | defaulted       |
| destructor          | defaulted           | user declared | defaulted        | defaulted       | not declared     | not declared    |
| copy constructor    | not declared        | defaulted     | user declared    | defaulted       | not declared     | not declared    |
| copy assignment     | defaulted           | defaulted     | defaulted        | user declared   | not declared     | not declared    |
| move constructor    | not declared        | defaulted     | deleted          | deleted         | user declared    | not declared    |
| move assignment     | defaulted           | defaulted     | deleted          | deleted         | not declared     | user declared   |

# C++ Idioms

---

# Rule of Three

The **Rule of Three** is a rule of thumb for C++(03)

If your class needs any of

- a copy constructor `X(const X&)`
- an assignment operator `X& operator=(const X&)`
- or a destructor `~X()`

defined explicitly, then it is likely to need all three of them

Some resources cannot or should not be copied. In this case, they should be declared as deleted

```
X(const X&) = delete
```

```
X& operator=(const X&) = delete
```

**Note:** many classes (such as `std` classes) manage resources themselves and should not implement copy/move constructor and assignment operator (**Rule of Zero**)

# Rule of Five

The **Rule of Five** is a rule of thumb for **C++11**

If your class needs any of

- a copy constructor `X(const X&)`
- a move constructor `X(X&&)`
- an assignment operator `X& operator=(const X&)`
- an assignment operator `X& operator=(X&&)`
- or a destructor `~X()`

defined explicitly, then it is likely to need all five of them



# Singleton

**Singleton** is a software design pattern that restricts the instantiation of a class to one and only one object

A common application is for logging

```
class Singleton {
public:
    static Singleton& get_instance() { // note "static"
        static Singleton instance { ..init.. } ;
        return instance; // destroyed at the end of the program
    } // initiliazied at first use

    Singleton(const& Singleton) = delete;
    void operator=(const& Singleton) = delete;
private:
    T _data;

    Singleton( ..args.. ) { // used in the initialization
        ...
    }
}
```

# PIMPL (Opaque Pointer)

**Pointer to IMPLementation (PIMPL)** idiom allow removing compilation dependencies on internal class implementations and improve compile times

header.hpp

```
class A {           // the class A is responsible to allocate
public:           // and deallocate Impl* ptr
    void f() {
        ptr->f();
    }
private:
    class Impl; // forward declaration
    Impl* ptr;  // opaque pointer
};
```

source.cpp (Impl actual implementation)

```
class A::Impl {
public:
    void f() {
        ..do something..
    }
};
```

The **Curiously Recurring Template Pattern (CRTP)** is an idiom in which a class `X` derives from a class template instantiation using `X` itself as template argument

A common application is *static polymorphism*

```
template <class T>
struct Base {
    void my_method() {
        static_cast<T*>(this)->implementation();
    }
};

class Derived : public Base<Derived> {
    // void my_method() is inherited
private:
    void my_method_impl() { ... }
};
```

```
#include <iostream>

template <class T>
struct Writer {
    void write(const char* str) {
        static_cast<const T*>(this)->write_impl(str);
    }
};

class CerrWriter : public Writer<CerrWriter> {
private:
    void write_impl(const char* str) { std::cerr << str; }
};

class CoutWriter : public Writer<CoutWriter> {
private:
    void write_impl(const char* str) { std::cout << str; }
};

int main() {
    CoutWriter x;
    CerrWriter y;
    x.write("abc");
    y.write("abc");
}
```

**Virtual functions cannot have template arguments**, but they can be emulated by using the following pattern

```
class Base {
public:
    template<typename T>
    void method(T t);    // here we want to emulate a virtual method
}
```

```
class Base {
public:
    template<typename T>
    void method(T t) {
        v_method(t);    // call the actual implementation
    }
private:
    virtual void v_method(int t)    = 0; // v_method is valid only
    virtual void v_method(double t) = 0; // for "int" and "double"
};
```

Actual implementations for derived class **A** and **B**

```
class AImpl : public Base {
protected:
    template<typename T>
    void t_method(T t) { // template "method()" implementation for A
        std::cout << "A " << t << std::endl;
    }
};

class BImpl : public Base {
protected:
    template<typename T>
    void t_method(T t) { // template "method()" implementation for B
        std::cout << "B " << t << std::endl;
    }
};
```

```
template<class Impl>
class DerivedWrapper : public Impl {
private:
    void v_method(int t) {
        Impl::t_method(t);
    }
    void v_method(double t) {
        Impl::t_method(t);
    } // call the base method
};

using A = DerivedWrapper<AImpl>;
using B = DerivedWrapper<BImpl>;
```

```
int main(int argc, char* argv[]) {
    A a;
    B b;
    Base* base = nullptr;

    base = &a;
    base->method(1); // print "A 1"
    base->method(2.0); // print "A 2.0"

    base = &b;
    base->method(1); // print "B 1"
    base->method(2.0); // print "B 2.0"
}
```

method() calls v\_method() (pure virtual method of Base )  
v\_method() calls t\_method() (actual implementation)

# Smart pointers

---



# Smart Pointers

**Smart pointer** is a pointer-like type with some additional functionality, e.g. *automatic memory deallocation* (when the pointer is no longer in use, the memory it points to is deallocated), reference counting, etc.

C++11 provides three smart pointer types:

- `std::unique_ptr`
- `std::shared_ptr`
- `std::weak_ptr`

Smart pointers prevent most situations of memory leaks by making the memory deallocation automatic

Full Story: [embeddedartistry.com](http://embeddedartistry.com)

# Smart Pointers Benefits

- If a smart pointer goes *out-of-scope*, the appropriate method to release resources is called automatically. The memory is not left dangling
- Smart pointers will automatically be set to `nullptr` if not initialized or when memory has been released
- `std::shared_ptr` provides automatic reference count
- If a special `delete` function needs to be called, it will be specified in the pointer type and declaration, and will automatically be called on delete

std::unique\_ptr is used to manage any dynamically allocated object that is not shared by multiple objects

```
#include <iostream>
#include <memory>
struct A {
    A() { std::cout << "Constructor\n"; } // called when A()
    ~A() { std::cout << "Destructor\n"; } // called when u_ptr1,
}; // u_ptr2 are out-of-scope

int main() {
    auto raw_ptr = new A();
    std::unique_ptr<A> u_ptr1(new A());
    std::unique_ptr<A> u_ptr2(raw_ptr);
    // std::unique_ptr<A> u_ptr3(raw_ptr); // no error, but wrong!!
    //                                     // (same pointer)
    // u_ptr1 = &raw_ptr; // compile error (unique pointer)
    // u_ptr1 = u_ptr2; // compile error (unique pointer)
    u_ptr1 = std::move(u_ptr2); // delete u_ptr1;
} // u_ptr1 = u_ptr2;
// u_ptr2 = nullptr
```

## std::unique\_ptr methods

- `get()` returns the underlying pointer
- `operator*` `operator->` dereferences pointer to the managed object
- `operator[]` provides indexed access to the stored array (if it supports random access iterator)
- `release()` returns a pointer to the managed object and releases the ownership
- `reset(ptr)` replaces the managed object with `ptr`

Utility method: `std::make_unique<T>()` creates a unique pointer of a class `T` that manages a new object

```
#include <iostream>
#include <memory>

struct A {
    int value;
};

int main() {
    std::unique_ptr<A> u_ptr1(new A());
    u_ptr1->value;      // dereferencing
    (*u_ptr1).value;   // dereferencing

    auto u_ptr2 = std::make_unique<A>(); // create a new unique pointer

    u_ptr1.reset(new A());           // reset
    auto raw_ptr = u_ptr1.release(); // release
    delete[] raw_ptr;

    std::unique_ptr<A[]> u_ptr3(new A[10]);
    auto& obj = u_ptr3[3];           // access
}
```

## Implements a custom deleter

```
#include <iostream>
#include <memory>

struct A {
    int value;
};

int main() {
    auto DeleteLambda = [](A* x) {
        std::cout << "delete" << std::endl;
        delete x;
    };

    std::unique_ptr<A, decltype(DeleteLambda)>
        x(new A(), DeleteLambda);
} // print "delete"
```

std::shared\_ptr is the pointer type to be used for memory that can be owned by multiple resources at one time

std::shared\_ptr maintains a reference count of pointer objects. Data managed by std::shared\_ptr is only freed when there are no remaining objects pointing to the data

```
#include <iostream>
#include <memory>
struct A {
    int value;
};
int main() {
    std::shared_ptr<A> sh_ptr1(new A());
    std::shared_ptr<A> sh_ptr2(sh_ptr1);
    std::shared_ptr<A> sh_ptr3(new A());
    sh_ptr3 = nullptr; // allowed, the underlying pointer is deallocated
                       // sh_ptr3 : zero references
    sh_ptr2 = sh_ptr1; // allowed // sh_ptr1, sh_ptr2: two references
    sh_ptr2 = std::move(sh_ptr1); // allowed // sh_ptr1: zero references
                                   // sh_ptr2: one references
}
```

`std::shared_ptr` methods

- `get()` returns the underlying pointer
- `operator*` `operator->` dereferences pointer to the managed object
- `use_count()` returns the number of objects referring to the same managed object
- `reset(ptr)` replaces the managed object with `ptr`

Utility method: `std::make_shared()` creates a shared pointer that manages a new object



```
#include <iostream>
#include <memory>
struct A {
    int value;
};

int main() {
    std::shared_ptr<A> sh_ptr1(new A());
    auto sh_ptr2 = std::make_shared<A>(); // std::make_shared
    std::cout << sh_ptr1.use_count(); // print 1

    sh_ptr1 = sh_ptr2; // copy
    // std::shared_ptr<A> sh_ptr2(sh_ptr1); // copy (constructor)
    std::cout << sh_ptr1.use_count(); // print 2
    std::cout << sh_ptr2.use_count(); // print 2

    auto raw_ptr = sh_ptr1.get(); // get
    sh_ptr1.reset(new A()); // reset

    (*sh_ptr1).value = 3; // dereferencing
    sh_ptr1->value = 2; // dereferencing
}
```

A `std::weak_ptr` is simply a `std::shared_ptr` that is allowed to dangle (pointer not deallocated)

```
#include <iostream>
#include <memory>

struct A {
    int value;
};

int main() {
    auto ptr = new A();
    std::weak_ptr<A> w_ptr(ptr);
    std::shared_ptr<A> sh_ptr(new A());

    sh_ptr = nullptr;
    // delete sh_ptr.get(); // double free or corruption

    w_ptr = nullptr;
    delete w_ptr; // ok valid
}
```

It must be converted to `std::shared_ptr` in order to access the referenced object

`std::weak_ptr` methods

- `use_count()` returns the number of objects referring to the same managed object
- `reset(ptr)` replaces the managed object with `ptr`
- `expired()` checks whether the referenced object was already deleted (`true`, `false`)
- `lock()` creates a `std::shared_ptr` that manages the referenced object

```
#include <iostream>
#include <memory>
struct A {
    int value;
};
int main() {
    auto sh_ptr1 = std::make_shared<A>();

    std::cout << sh_ptr1.use_count(); // print 1
    std::weak_ptr<A> w_ptr = sh_ptr1;
    std::cout << w_ptr.use_count(); // print 1

    auto sh_ptr2 = w_ptr.lock();
    std::cout << sh_ptr2.use_count(); // print 2 (sh_ptr1 + sh_ptr2)

    sh_ptr1 = nullptr;
    std::cout << w_ptr.expired(); // print false

    sh_ptr2 = nullptr;
    std::cout << w_ptr.expired(); // print true
}
```

# Concurrency

---

# Overview

C++11 introduces the **Concurrency** library to simplify managing OS threads

```
#include <iostream>
#include <thread>

void f() {
    std::cout << "first thread" << std::endl;
}

int main(){
    std::thread th(f);
    th.join();           // stop the main thread until "th" complete
}
```

How to compile:

```
$g++ -std=c++11 main.cpp -pthread
```

# Example

```
#include <iostream>
#include <thread>
#include <vector>

void f(int id) {
    std::cout << "thread " << id << std::endl;
}

int main() {
    std::vector<std::thread> thread_vect; // thread vector
    for (int i = 0; i < 10; i++)
        thread_vect.push_back( std::thread(&f, i) );

    for (auto& th : thread_vect)
        th.join();

    thread_vect.clear();
    for (int i = 0; i < 10; i++) { // thread + lambda expression
        thread_vect.push_back(
            std::thread( [](){ std::cout << "thread\n"; } ) );
    }
}
```

## Library methods:

- `std::this_thread::get_id()` returns the thread id
- `std::thread::sleep_for( sleep_duration )`  
Blocks the execution of the current thread for at least the specified `sleep_duration`
- `std::thread::hardware_concurrency()` returns the number of concurrent threads supported by the implementation

## Thread object methods:

- `get_id()` returns the thread id
- `join()` waits for a thread to finish its execution
- `detach()` permits the thread to execute independently from the thread handle



```
#include <chrono> // the following program should (not deterministic)
#include <iostream> // produces the output:
#include <thread> // child thread exit
                // main thread exit

int main() {
    using namespace std::chrono_literals;
    std::cout << std::this_thread::get_id();
    std::cout << std::thread::hardware_concurrency(); // e.g. print 6

    auto lambda = []() {
        std::this_thread::sleep_for(1s); // t2
        std::cout << "child thread exit\n";
    };
    std::thread child(lambda);
    child.detach(); // without detach(), child must join() the
                  // main thread (run-time error otherwise)
    std::this_thread::sleep_for(2s); // t1
    std::cout << "main thread exit\n";
}

// if t1 < t2 the should program prints:
// main thread exit
```

# Parameters Passing

Parameters passing *by-value* or *by-pointer* to a thread function works in the same way of a standard function. *Pass-by-reference* requires a special wrapper ( `std::ref` , `std::cref` ) to avoid wrong behaviors

```
#include <iostream>
#include <thread>
void f(int& a, const int& b) {
    a = 7;
    const_cast<int&>(b) = 8;
}
int main() {
    int a = 1, b = 2;
    std::thread th1(f, a, b);                // wrong!!!
    std::cout << a << ", " << b << std::endl; // print 1, 2!!

    std::thread th2(f, std::ref(a), std::cref(b)); // correct
    std::cout << a << ", " << b << std::endl; // print 7, 8!!
    th1.join(); th2.join();
}
```

The following code produces (in general) a value  $< 1000$ :

```
#include <chrono>
#include <iostream>
#include <thread>
#include <vector>
void f(int& value) {
    for (int i = 0; i < 10; i++) {
        value++;
        std::this_thread::sleep_for(std::chrono::milliseconds(10));
    }
}
int main() {
    int value = 0;
    std::vector<std::thread> th_vect;
    for (int i = 0; i < 100; i++)
        th_vect.push_back( std::thread(f, std::ref(value)) );

    for (auto& it : th_vect)
        it.join();
    std::cout << value;
}
```

C++11 provide the `mutex` class as synchronization primitive to protect shared data from being simultaneously accessed by multiple threads

`mutex` methods:

- `lock()` locks the *mutex*, blocks if the *mutex* is not available
- `try_lock()` tries to lock the *mutex*, returns if the *mutex* is not available
- `unlock()` unlocks the *mutex*

More advanced mutex can be found here: [en.cppreference.com/w/cpp/thread](http://en.cppreference.com/w/cpp/thread)

C++ includes three mutex wrappers to provide safe copyable/movable objects:

- `lock_guard` (C++11) implements a strictly scope-based mutex ownership wrapper
- `unique_lock` (C++11) implements movable mutex ownership wrapper
- `shared_lock` (C++14) implements movable shared mutex ownership wrapper

```
#include <chrono>
#include <iostream>
#include <thread>
#include <vector>

void f(int& value, std::mutex& m) {
    for (int i = 0; i < 10; i++) {
        m.lock();
        value++;    // other threads must wait
        m.unlock();
        std::this_thread::sleep_for(std::chrono::milliseconds(10));
    }
}

int main() {
    std::mutex m;
    int value = 0;
    std::vector<std::thread> th_vect;
    for (int i = 0; i < 100; i++)
        th_vect.push_back( std::thread(f, std::ref(value), std::ref(m)) );
    for (auto& it : th_vect)
        it.join();
    std::cout << value;
}
```

# Atomic

`std::atomic` (C++11) template class defines an atomic type that are implemented with lock-free operations (much faster than locks)

```
#include <atomic>
... // include also: chrono, iostream, thread, vector

void f(std::atomic<int>& value) {
    for (int i = 0; i < 10; i++) {
        value++;
        std::this_thread::sleep_for(std::chrono::milliseconds(10));
    }
}

int main() {
    std::atomic<int> value(0);
    std::vector<std::thread> th_vect;
    for (int i = 0; i < 100; i++)
        th_vect.push_back( std::thread(f, std::ref(value)) );
    for (auto& it : th_vect)
        it.join();
    std::cout << value;    // print 1000
}
```

The `future` library provides facilities to obtain values that are returned and to catch exceptions that are thrown by *asynchronous* tasks

Asynchronous call: `std::future async(function, args...)`  
runs a function asynchronously (potentially in a new thread)  
and returns a `std::future` object that will hold the result

`std::future` methods:

- `T get()` returns the result
- `wait()` waits for the result to become available

`async()` can be called with two launch policies for a task executed:

- `std::launch::async` a new thread is launched to execute the task asynchronously
- `std::launch::deferred` the task is executed on the calling thread the first time its result is requested (lazy evaluation)

```
#include <iostream>
#include <vector>
#include <algorithm>
#include <numeric>
#include <future>
template <typename RandomIt>
int parallel_sum(RandomIt beg, RandomIt end) {
    auto len = end - beg;
    if (len < 1000)    // base case
        return std::accumulate(beg, end, 0);

    RandomIt mid = beg + len / 2;
    auto handle = std::async(std::launch::async, // right side
                             parallel_sum<RandomIt>, mid, end);
    int sum = parallel_sum(beg, mid);           // left side
    return sum + handle.get();                 // left + right
}
int main() {
    std::vector<int> v(10000, 1); // init all to 1
    std::cout << "The sum is " << parallel_sum(v.begin(), v.end());
}
```



# C++ Guidelines

---

## C++ Core Guidelines

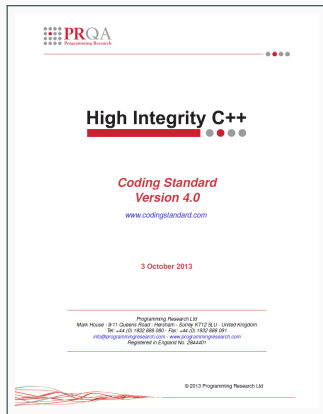
Authors: Bjarne Stroustrup, Herb Sutter



## CORE GUIDELINES

*The guidelines are focused on relatively high-level issues, such as interfaces, resource management, memory management, and concurrency. Such rules affect application architecture and library design. Following the rules will lead to code that is statically type safe, has no resource leaks, and catches many more programming logic errors than is common in code today*

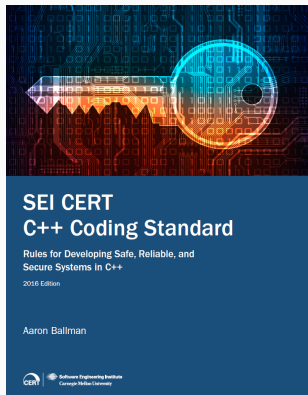
## High Integrity C++ Coding Standard (HIC++)



*This document defines a set of rules for the production of high quality C++ code. The guiding principles of this standard are maintenance, portability, readability and robustness*

## CERT C++ Secure Coding

Author: Aaron Ballman



*This standard provides rules for secure coding in the C++ programming language. The goal of these rules is to develop safe, reliable, and secure systems, for example by eliminating undefined behaviors that can lead to undefined program behaviors and exploitable vulnerabilities*