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C++11: An Overview

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Bjarne Stroustrup about C++11



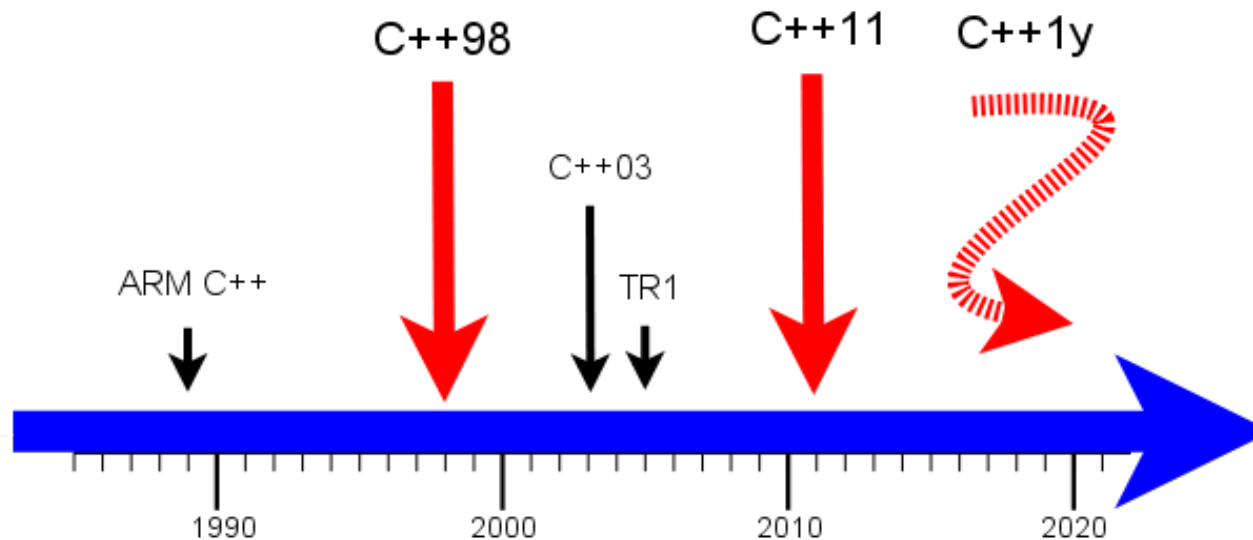
*Bjarne Stroustrup:
„Surprisingly, C++11 feels like a
new language - the pieces just fit
together better.“*



(source:<http://www.wojcik.net>; 2012-02-28)

- the past: C++98
- the present: C++11
 - core language
 - multithreading
 - standard library
- the future: C++1y

Timeline



- ARM C++: “The Annotated C++ Reference Manual”
- **C++98**: first ISO Standard
 - C++03: technical corrigendum of C++98
 - TR1: technical report 1
- **C++11**: current ISO Standard
- **C++1y**: future ISO Standard



- Principles of C++:
 - Trust the programmer.
 - You don't have to pay for something you don't need.
 - Don't break existing code.
 - Prefer compile time errors over run time errors.
- Aims for C++11:
 - Is the better programming language
 - for system programming.
 - for the building of libraries.
 - Is easier to teach and to learn.

Deduction of the type with `auto`

- The compiler determines the type:

```
auto myString= "my String";           // C++11  
auto myInt= 5;                         // C++11  
auto myDouble= 3.14;                  // C++11
```

- Get a iterator on the first element of a vector:

```
vector<int> v;  
vector<int>::iterator it1= v.begin();   // C++98  
auto it2= v.begin();                  // C++11
```

- Definition of a function pointer:

```
int add(int a,int b){ return a+b; };  
int (*myAdd1)(int,int)= add;           // C++98  
auto myAdd2= add;                      // C++11  
myAdd1(2,3) == myAdd2(2,3);
```

Deduction of the type with `decltype`

- The compiler determines the type of an expression:

```
decltype("str") myString= "str";           // C++11
decltype(5) myInt= 5;                       // C++11
decltype(3.14) myFloat= 3.14;              // C++11
decltype(myInt) myNewInt= 2011;            // C++11

int add(int a,int b){ return a+b; };
decltype(add) myAdd= add; // (int) (*) (int, int) // C++11
myAdd(2,3) == add(2,3);
```

Deduce the return type of a function

- Example for the new alternative function syntax:
 func(arguments) → return value { functionbody }

- A generic add function with **auto** and **decltype**:

```
template <typename T1, typename T2>  
auto add(T1 first, T2 second) -> decltype(first + second) {  
    return first + second;  
}
```

```
add(1,1);
```

```
add(1,1.1);
```

```
add(1000LL, 5);
```

- the result is of type

```
int
```

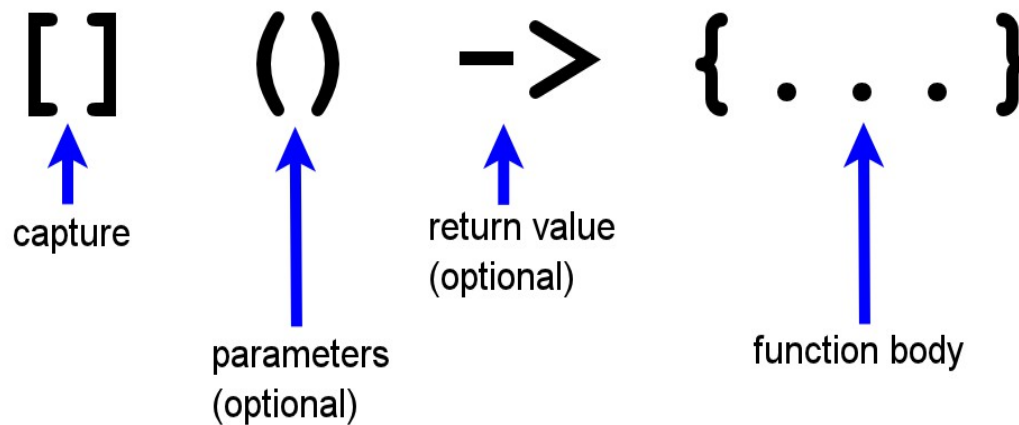
```
double
```

```
long long int
```




- Lambda functions
 - are functions without name.
 - define their functionality right in place.
 - can be copied like data.
- Lambda functions should be
 - concise.
 - self explaining.

Lambda functions: Syntax



- `[]` : captures the used variables per copy of per reference
- `()` : is required for parameters
- `->` : is required for sophisticated lambda functions
- `{ }` : may include expressions and statements

Lambda functions

- Sort the elements of a vector:

```
vector<int> vec={3,2,1,5,4};
```

- in C++98 with a function object

```
class MySort{  
public:  
    bool operator()(int v, int w){ return v > w; }  
};  
// a lot of code  
sort(vec.begin(),vec.end(),MySort());
```

- in C++11 with a lambda function:

```
sort(vec.begin(),vec.end(),  
    [](int v,int w){  
        return v > w;  
    });  
sort(vec.begin(),vec.end(),[](int v,int w){return v>w;});
```

- Lambda functions can do much more:

- starting a thread:

```
thread t1([]{cout << this_thread::get_id() << endl;});  
thread t2([]{veryExpensiveFunction();});
```

- Lambda functions are first-class functions:

- argument of a function:

```
auto myLambda= []{return "lambda function";};  
getLambda(myLambda);
```

- return value of a function:

```
function< string() > makeLambda{  
    return []{return "2011";};  
};
```

Simple and unified initialization

- Simple data type:

```
int i{2011};  
string st= {"Stroustrup"};
```

- Container:

```
vector<string> vec= {"Scott", st, "Sutter"};  
unordered_map<string, int> um= {"C++98", 1998}, {"C++11", i}];
```

- Array as a member of a class:

```
struct MyArray{  
    MyArray(): myData{1, 2, 3, 4, 5} {}  
    int myData[5];  
}
```

- Const heap array:

```
const float* pData= new const float[5]{1, 2, 3, 4, 5};
```

The range-based for-loop

- Simple iteration over a container:

```
vector<int> vec={1,2,3,4,5};  
for (auto v: vec) cout << v << ", ";           // 1,2,3,4,5,
```

```
unordered_map<string,int> um= {"C++98",1998}, {"C++11",2011}};  
for (auto u:um) cout << u->first << ":" << u->second << " ";  
// "C++11":2011 "C++98":1998
```

- Modifying the container elements by **auto&**:

```
for (auto& v: vec) v *= 2;  
for (auto v: vec) cout << v << " ,";           // 2,4,6,8,10,
```

```
string testStr{"Only for Testing."};  
for (auto& c: testStr) c= toupper(c);  
for (auto c: testStr) cout << c; // "ONLY FOR TESTING."
```

Constructor: Delegation

```
class MyHour{
    int myHour_;
public:
    MyHour(int h){ // #1
        if (0 <= h and h <= 23 ) myHour_ = h;
        else myHour_ = 0;
    }
    MyHour(): MyHour(0){}; // #2
    MyHour(double h): MyHour(static_cast<int>(ceil(h))){}; // #3
};
```

➔ The constructors #2 and #3 invoke the constructor #1.

Constructor: Inheritance (using)

```
struct Base{
    Base(int) {}
    Base(string) {}
};
struct Derived: public Base{
    using Base::Base;
    Derived(double) {}
};
int main() {
    Derived(2011);           // Base::Base(2011)
    Derived("C++11");       // Base::Base(C++11)
    Derived(0.33);          // Derived::Derived(0.33)
}
```


Requesting methods (default)

- Requesting special methods and operators from the compiler:
 - default - and copy - constructor;
assignment operator, operator new;
destructor

```
class MyType{  
    public:  
        MyType(int val) {} // #1  
        MyType()= default; // #2  
        virtual ~MyType();  
        MyType& operator= (MyType&)  
};  
MyType::~~MyType()= default;  
MyType& MyType::operator(MyType&)= default;
```

- #1 suppresses the automatic generation of #2.

Suppress function invocations (delete)

- Not copyable classes:

```
class NonCopyClass{
    public:
        NonCopyClass()= default;
        NonCopyClass& operator =(const NonCopyClass&)= delete;
        NonCopyClass (const NonCopyClass&)= delete;
};
```

- A function only accepting double:

```
void onlyDouble(double){}
template <typename T> void onlyDouble(T)= delete;
int main(){
    onlyDouble(3);
};
```

➔ Error: use of deleted function »void onlyDouble(T) [with T = int]«

Explicit override (override)

- Control by the compiler:

```
class Base {
    virtual void func1();
    virtual void func2(float);
    virtual void func3() const;
    virtual long func4(int);
};

class Derived: public Base {
    virtual void func1() override;           // ERROR
    virtual void func2(double) override;    // ERROR
    virtual void func3() override;          // ERROR
    virtual int func4(int) override;         // ERROR
    virtual long func4(int) override;       // OK
};
```

Suppress override (`final`)

- For methods:

```
class Base {  
    virtual void h(int) final;  
};  
class Derived: public Base {  
    virtual void h(int);           // ERROR  
    virtual void h(double);      // OK  
};
```

- For classes:

```
struct Base final{};  
struct Derived: Base{};           // ERROR
```

Rvalue references

- rvalue references are special references that can be bind to a rvalue.
- rvalues are
 - temporary.
 - objects without name.
 - objects, of which can not be determined an address.

- rvalue references are defined with 2 and symbols (&&):

```
MyData myData;
```

```
MyData& myDataLvalue= myData;
```

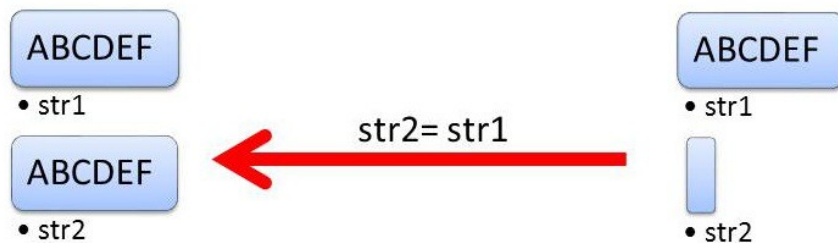
```
MyData&& myDataRvalue( MyData());
```

- The compiler can bind lvalue references to an lvalue, rvalue references to an rvalue.
 - ➔ Special action can be given for rvalues.
- Use case: move semantic and perfect forwarding.

Move semantic (`move`)

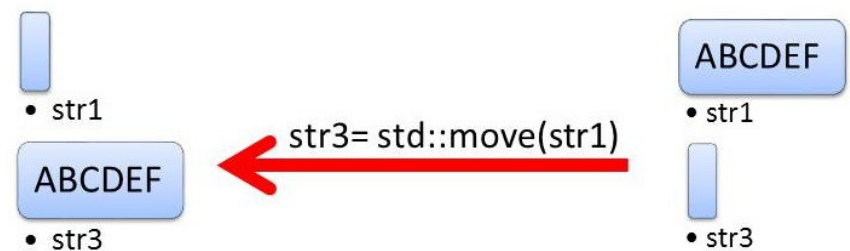
Copy

```
string str1("ABCDEF");  
string str2;  
str2= str1;
```



Move

```
string str1{"ABCDEF"};  
string str3;  
str3= std::move(str1);
```



- Advantages:

- cheap moving of a resource instead of expensive copying:

```
vector<int> myBigVector;
```

```
.....
```

```
vector<int> myBigVector2 (move (myBigVector) );
```

- Not copyable but moveable objects can be given to or by a function *by value*.

- Examples: `unique_ptr`, files, `mutex`, `promise` and `future`

```
mutex m;
```

```
unique_lock<mutex> uniqueLock (m) ;
```

```
unique_lock<mutex> uniqueLock2 (move (m) ) ;
```

Perfect forwarding (`forward`)

- Enables to write function templates, which can forward their argument to a further function preserving the lvalue/rvalue items of the arguments.
 - Stroustrup: „ . . . a heretofore unsolved problem in C++.“
- Use case: factory function or constructor
- Example: factory function with one argument

```
template <typename T, typename T1>
T createObject(T1&& t1) {
    return T(forward<T1>(t1));
}

int myFive2= createObject<int>(5);           // Rvalue
int five=5;
int myFive= createObject<int>(five);       // Lvalue
```


Variadic templates (. . .)

- Templates, which can get an arbitrary number of arguments
- The ellipse `...` denotes the template parameter pack, that can be packed or unpacked.
- Application: `std::tuple`, `std::thread`
- Example: a completely generic factory function

```
template <typename T, typename ... Args>
T createObject(Args&& ... args) {
    return T(forward<Args>(args)...);
}

string st= createObject<string>("Rainer");
struct MyStruct{
    MyStruct(int i, double d, string s) {}
};

MyStruct myStr= createObject<MyStruct>(2011, 3.14, "Rainer");
```

More control at compile time

(`static_assert`)

- Has no influence on the run time of the program.
- `static_assert` can be combined very well with the new type traits library.
- Assert:

- a 64-bit architecture:

```
static_assert(sizeof(long) >= 8, "no 64-bit code");
```

- an arithmetic type:

```
template< typename T >  
struct Add{  
    static_assert(is_arithmetic<T>::value, "T is not arith");  
};
```

const expressions (**constexpr**)

- Is an optimisation opportunity for the compiler:
 - Can be evaluated at compile time.
 - The compiler gets a deep insight in the evaluated code.
- Three types:

- variables:

```
constexpr double myDouble= 5.2;
```

- functions:

```
constexpr fact (int n){return n > 0 ? n * fact(n-1) : 1;}
```

- user defined types:

```
struct MyDouble{  
    double myVal;  
    constexpr MyDouble(double v) : myVal(v) {}  
};
```

Raw string literales (r“(raw string)“)

- Suppress the interpretation of the string
- Defined with r“(raw string)“ or R“(Raw String)“
- Are practical helper for:

- paths:

```
string pathOld= "C:\\temp\\newFile.txt";  
string pathRaw= r"(C:\temp\newFile.txt)";
```

- regular expressions:

```
string regOld= "c\\+\\+";  
string regRaw= r"(c\+\+)";
```

What I further want to say

- Design of classes:

- in-class member initialization:

```
class MyClass{  
    const static int oldX= 5;  
    int newX= 5;  
    vector<int> myVec{1,2,3,4,5};  
};
```

- Extended data concepts:

- unicode support: UTF-16 und UTF-32
 - user defined literales: `63_s`; `123.45_km`; `"Hallo"_i18n`
 - the null pointer literal `nullptr`

Multithreading

C++11's answer to the requirements of the multi-core architectures.



(source: <http://www.livingroutes.org>, 2012-02-28)

- ➔ a standardized threading interface
- ➔ a defined memory model

Thread versus task

- **thread**

```
int res;  
thread t([&]{res= 3+4;});  
t.join();  
cout << res << endl;
```

- **task**

```
auto fut=async([]{return 3+4;});  
cout << fut.get() << endl;
```

aspect	thread	task
communication	shared variable	channel between father and child
thread creation	obligatory	optional
synchronisation	the father is waiting for his child	the <code>get</code> -invocation is blocking
exception in the child	child and father terminates	return value of the <code>get</code> -invocation

Threads (**thread**)

- A thread will be parametrized with its working package and starts immediately.
- The father thread:

```
thread t([]{ cout << "I'm running." << endl;});
```

- has to wait for its child:

```
t.join();
```

- needs to separate itself from the child (daemon thread):

```
t.detach();
```

- ➔ data should be copied per default into child thread:

```
string s{"undefined behavior"};
```

```
thread t([&]{ cout << s << endl;});
```

```
t.detach();
```


Thread-local data (`thread_local`)

- Are unique to a thread
- Behave like static variables

```
void addThreadLocal(string const& s){  
    thread_local threadLocalStr("Hello from ");  
    threadLocalStr += s;  
    cout << threadLocalStr << endl;  
}
```

```
thread t1(addThreadLocal, "t1");
```

```
thread t2(addThreadLocal, "t2");
```

- ➔ **Result: Hello from t1**
Hello from t2

Protection of data (**mutex**)

- Shared variables have to be protected against race conditions.
- **race condition:** Two or more threads use a shared variable at the same time, and at least one of them is a write access.
- A mutex (**mutual exclusion**)
 - ensures the mutual exclusion
 - exists in C++11:
 - in recursive and not recursive way.
 - with and without relative and absolute time.

Deadlocks with mutexes

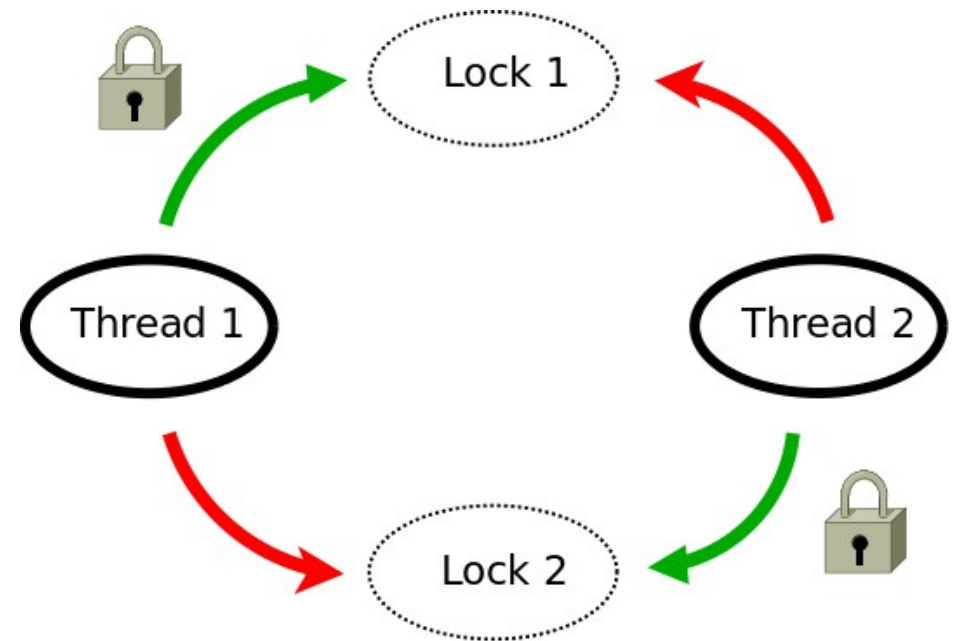
Exception:

- mutex in use:

```
mutex m;  
m.lock();  
sharedVar= getVar();  
m.unlock();
```

- Problem: An exception in `getVar()` can result in a deadlock.

Acquire the lock in different order:



➔ Use `lock_guard` and `unique_lock`.

RAII with `lock_guard` and `unique_lock`

- `lock_guard` and `unique_lock` manage the lifetime of their mutex according to the RAII idiom.

- `lock_guard`:

```
mutex mapMutex;  
{  
    lock_guard<mutex> mapLock (mapMutex) ;  
    addToMap ("white", 0) ;  
}
```

- `unique_lock` for the more advanced use
 - Set or release explicit the lock.
 - Move or swap the lock.
 - Tentative or delayed locking.

Initialisation of shared variables

- Variables, that are read-only, have only to be initialised in a secure manner.
 - ➔ The expensive locking of the variable is not necessary.

- C++11 offers 3 opportunities:

1) constant expressions:

```
constexpr MyDouble myDouble;
```

2) `call_once` and `once_flag`:

```
void onlyOnceFunction() { ..... };  
once_flag onceFlag;  
call_once(onceFlag, onlyOnceFunction)
```

3) static local variables:

```
void func() { ... static int a=2011; ... }
```

Condition variables (**notify_one**, **wait**)

- a sender – a receiver:

```
mutex protVarMutex;  
condition_variable condVar;  
bool dataReady;
```

thread 1: sender

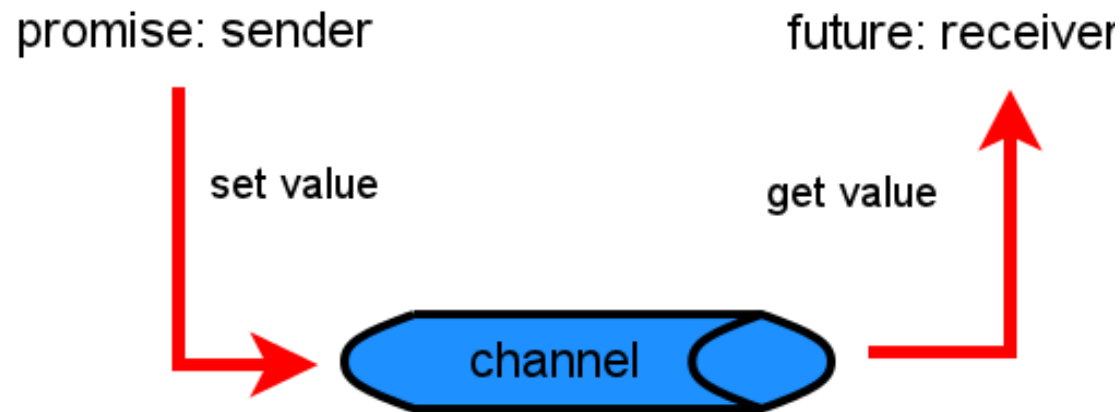
```
lock_guard<mutex> sender_lock(protVarMutex);  
protectedVar= 2000;  
dataReady= true;  
condVar.notify_one();
```

thread 2 : receiver

```
unique_lock<mutex> receiver_lock(protVarMutex);  
condVar.wait(receiver_lock, []{return dataReady;});  
protectedVar += 11;
```

- a sender - many receivers (**notify_all** and **wait**)

Promise and future as data channel



- The promise
 - sends the data
 - can serve many futures
 - can send values, exceptions and notifications
- The future
 - is the data receiver
 - the `get`-invocation is blocking

Promise and future in use

```
a=2000;
```

```
b=11;
```

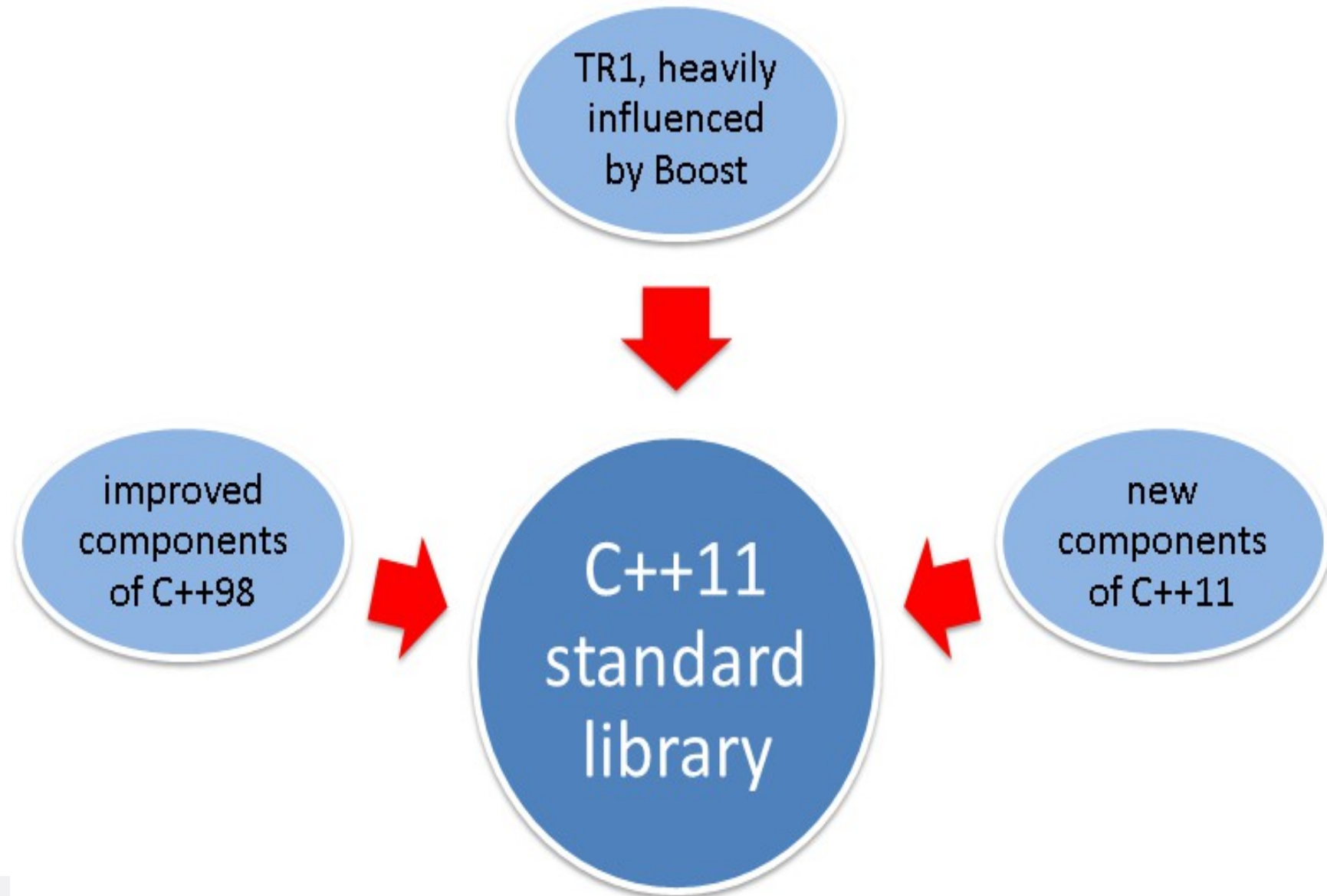
- **Implicitly by `async`**

```
future<int> sum= async( [= ] { return a+b; } );  
sum.get();
```

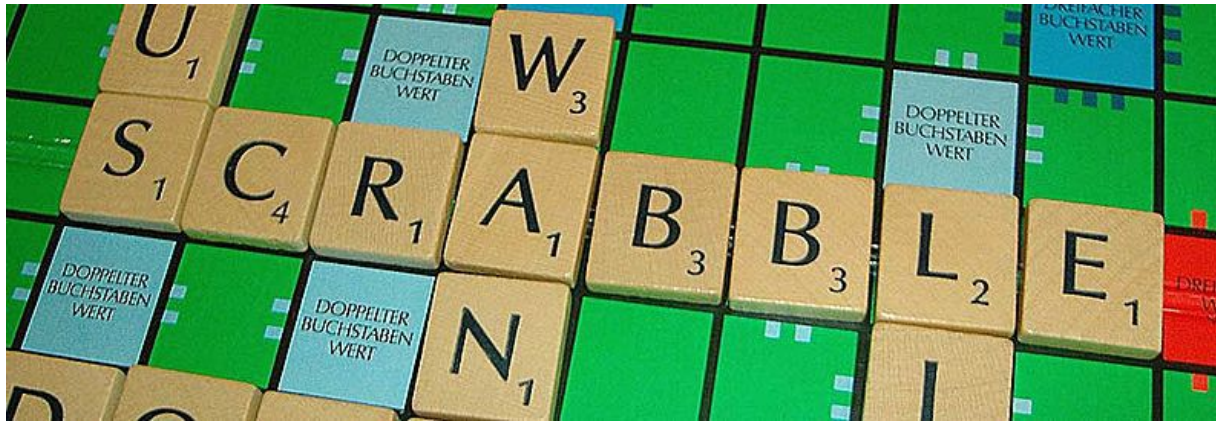
- **Explicitly by `future` and `promise`**

```
void sum(promise<int>&& intProm, int x, int y) {  
    intProm.set_value(x+y);  
}  
  
promise<int> sumPromise;  
future<int> futRes= sumPromise.get_future();  
thread sumThread(&sum, move(sumPromise), a, b);  
  
futRes.get();
```


Influences on the new standard library



Regular expressions



- is a formal language for describing text patterns
- is the tool for text manipulation:
 - is a text equal to a text pattern?
 - search for a text pattern in a text
 - substitute a text pattern in a text
 - iterate over all text patterns in a text

Regular Expressions: Example

- Search for the first occurrence of a number in a text:

```
string text("abc1234def");  
string regExNumber(r"(\d+)");  
smatch holdResult;  
if ( regex_search(text,holdResult,regExNumber) )  
    cout << holdResult[0] << endl;  
    cout << holdResult.prefix() << endl;  
    cout << holdResult.suffix() << endl;
```

➔ Result: 1234

abc

def

- Iterate over all numbers in a text:

```
string text="Der bisherige Standard C++98 ist nach 13  
Jahren am 12. August 2011 durch den neuen Standard C++11  
abgelöst worden."  
regex regNumb(r"(\d+)");  
sregex_token_iterator it(text.begin(),text.end(),regNumb);  
sregex_token_iterator end;  
while (it != end) cout << *it++ << " ";
```

➔ Result: 98 13 12 2011 11

- Enable at compile time:

- type queries (`is_integral<T>`, `is_same<T, U>`)

```
template <typename T>
T gcd(T a, T b) {
    static_assert(is_integral<T>::value, "not integral");
    if( b==0 ) return a;
    else return gcd(b, a % b);
}
```

- type transformations (`add_const<T>`)

```
typedef add_const<int>::type myConstInt;
cout << is_same<const int, myConstInt>::value << endl;
```

- ➔ Result: true

- ➔ Code, which is self-tuning

- combines a random number generator with a random number distribution:
 - random number generator:
 - creates a stream of random numbers between a minimum and maximum value
 - examples: Mersenne Twister, `random_device` (`/dev/urandom`)
 - random number distribution:
 - maps the random numbers on the distribution
 - examples: uniform, normal, poisson and gamma distribution
- Throw of a dice:

```
random_device seed;  
mt19337 numberGenerator(seed());  
uniform_int_distribution<int> six(1,6);  
cout << six(numberGenerator) << endl;
```

// 3

- Elementary component of the new multithreading functionality:
- Examples:

- Put the actual thread for 100 milliseconds to sleep:

```
this_thread::sleep_for( chrono::millisecond(100) );
```

- performance measurement in seconds:

```
auto begin= chrono::system_clock::now();
```

```
// a lot to do
```

```
auto end= chrono::system_clock::now() - begin;
```

```
auto timeInSeconds= chrono::duration<double>(end).count();
```

Reference wrapper (`reference_wrapper`)

- `reference_wrapper<T>` is a copy constructible and assignable wrapper around an object of type `T&`.
 - ➔ behaves as a reference, but can be copied
- New use cases:

1. classes containing references can be copied:

```
struct Copyable{  
    Copyable(string& s): name(s){}  
    // string& badName; will not compile  
    reference_wrapper<string> name;  
};
```

2. references can be used inside containers of the STL:

```
int a=1, b=2, c=4;  
vector<reference_wrapper<int>> vec={ref(a), ref(b), ref(c)};  
c = 3;
```

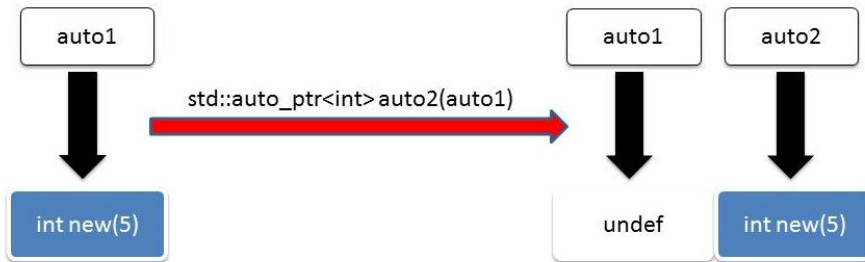
➔ Result: `vec[2] == 3`

Smart pointer: lifecycle management

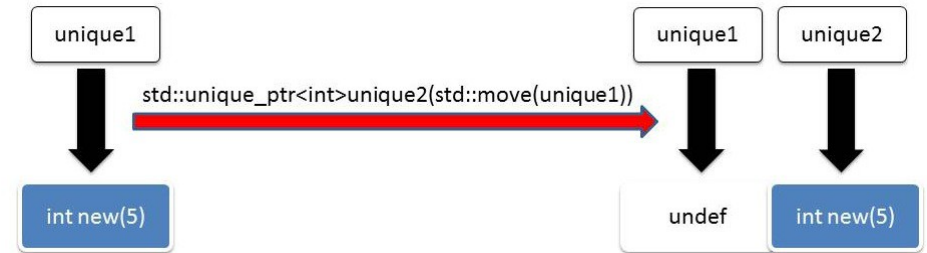
name	C++ standard	description
auto_ptr	C++98	<ul style="list-style-type: none">owns exclusive the resourcemoves the resource silently while copying
unique_ptr	C++11	<ul style="list-style-type: none">owns exclusive the resourcean not be copiedcan manage not copyable objects (threads,locks, files, ...)
shared_ptr	C++11	<ul style="list-style-type: none">has a reference counter for his resourcemanage automatically the reference counterdeletes the resource, if the reference count is 0

Smart pointer: *copying*

auto_ptr



unique_ptr



shared_ptr



Smart pointer in use

```
shared_ptr<int> sharedPtr(new int(5));           // refcount == 1
{
    shared_ptr<int> localSharedPtr(sharedPtr);   // refcount == 2
}                                               // refcount == 1
shared_ptr<int> globalSharedPtr= sharedPtr;    // refcount == 2
globalSharedPtr.reset();                       // refcount == 1
```

```
unique_lock<int> uniqueInt(new int(2011));
unique_lock<mutex> uniqueInt2(uniqueInt);      // error !!!
unique_lock<mutex> uniqueInt2(move(uniqueInt));
vector<std::unique_ptr<int>> myIntVec;
myIntVec.push_back(move(uniqueInt2));
```

New container (tuple and array)

- tuple:

- heterogeneous container of fixed length
- extension of the container pair from C++98:

```
tuple<string,int,float> tup=("first",1998,3.14);  
auto tup2= make_tuple("second",2011,'c');  
get<1>(tup)= get<1>(tup2);
```

- array:

- homogeneous container of fixed length
- combines the performance of a C array with the interface of a C++ vector:

```
array<int,8> arr{{1,2,3,4,5,6,7,8}};  
int sum= 0;  
for_each(arr.begin(),arr.end(), [&sum](int v){sum += v;});
```

New container (hash tables)

- consists of (key,value) pairs
- also known as dictionary or associative array
- unordered variant of the C++ container map, set, multimap and multiset
- 4 variations:

name	has value	more equal keys
<code>unordered_map</code>	yes	no
<code>unordered_set</code>	no	no
<code>unordered_multimap</code>	yes	yes
<code>unordered_multiset</code>	no	yes

- comparison of the C++11 with the C++98 containers:
 - very similar interface
 - keys unordered
 - constant access time

New container (hash tables)

```
map<string,int> m {{"Dijkstra",1972},{"Scott",1976}};  
m["Ritchie"] = 1983;  
for(auto p : m) cout << '{' << p.first << ',' << p.second << '}'  
  
cout << endl;
```

```
unordered_map<string,int> um { {"Dijkstra",1972},{"Scott",1976}};  
um["Ritchie"] = 1983;  
for(auto p : um) cout << '{' << p.first << ',' << p.second << '}'
```

- Result: {Dijkstra,1972}{Ritchie,1983}{Scott,1976}
 {Ritchie,1983}{Dijkstra,1972}{Scott,1976}

- Feature for the functional programming:
 - `bind` allows to easily build functions object.
 - `function` binds the function objects from `bind`.

```
int add(int a, int b){ return a+b;};  
function< int(int)> myAdd= bind(add,2000,_1);  
add(2000,11) == myAdd(11);
```
- Both libraries are due to the core language extension nearly superfluous:
 - For `bind` you can use lambda functions.
 - For `function` you can use `auto`:

```
auto myAddLambda= [](int v){ return add(2000,v); };  
add(2000,11) == myAddLambda(11);
```

Predictions are difficult, especially when they concern the future.



(source: www.nato.int; 2012-02-28)

- time frame for C++1y: 2017
- extension of the library:
 - Technical Report with file system
- content
 - constrained templates (2022)
 - multithreading
 - STM (2022)
 - asynchronous IO
 - modules
 - libraries

C++11: An overview



Vielen Dank für Ihre Aufmerksamkeit.

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