Modern C++

New features in (mostly) C++11
but also 14, 17, and 20

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Resources

- ISO C++: https://isocpp.org/
- CppReference: https://en.cppreference.com/w/
- Cpp Core Guidelines: https://github.com/isocpp/CppCoreGuidelines
- *A Tour of C++*: http://www.stroustrup.com/Tour.html
- Compiler Explorer: https://godbolt.org/
- Conferences and videos:
  - CppCon: https://www.youtube.com/CppCon
  - C++Now: www.youtube.com/BoostCon
- Podcasts: CppCast, CppChat
- Blogs: http://www.fluentcpp.com/

Contents

C++ History

Early Goals of C++:

(source) https://isocpp.org/wiki/faq/cpp11#cpp11-goals

"C++ has from its inception been a general-purpose programming language with a bias towards systems programming that:

- *is a better C*
- *supports data abstraction*
- *supports object-oriented programming*
- *supports generic programming"*

Pre-Modern C++ History

- 1979: Bjarne starts work on “C With Classes starts” - Classes, public/private, constructors and destructors
- 1984: Renamed “C++” - Virtual functions, operator overloading, references, and I/O streams
- 1985: First commercial release of C++
- 1998: ISO C++ standard - Templates, exceptions, RAII, namespaces, The STL.
- 2002: Work on revised standard (C++0x) begins
- 2003: *“Bugfix”* C++03 released

Modern C++ History

- **2011: C++0x becomes C++11, and is finally approved and released after 13 years**
  - Type deduction, smart pointers, move semantics, lambdas, updated memory model, locks, mutex
- **2014: *"Bugfix"* C++14 released. Seen as "completing" C++11**
  - Variable templates, digit separators, generic lambdas, and a few standard-library improvements
- **2017: C++17 release, Cpp Core Guidelines Formalized**
  - Structured bindings, fold expressions, a file system library, parallel algorithms, and variant and optional types
- **2020: C++20 standard to be approved, the next "Major" release like C++11:**
  - Modules, Ranges, Concepts, Contracts
  - Post-Modern C++?

Design Goals of C++11

- Stability: don’t break old code
- Prefer libraries to language extensions: Not always successful
- Prefer generality to specialization: focus on improving abstraction mechanisms
- Support both experts and novices
- Increase type safety: Allow programmers to avoid type-unsafe features
- Improve performance and ability to work directly with hardware – make C++ even better for embedded systems programming and high-performance computation
- Retain Zero-Cost abstractions. Don’t pay for features you don’t use.
- Fit into the real world – consider tool chains, implementation cost, transition problems, ABI issues, teaching and learning, etc.

  https://isocpp.org/wiki/faq/cpp11#cpp11-specific-goals

C++ Programming Philosophy

- Stack-based scope instead of heap or static global scope.
- Auto type inference instead of explicit type names.
- Smart pointers for ownership instead of raw pointers.
- `std::string` types instead of raw `char[]` arrays.
- Use C++ Standard Library containers like `vector`, `list`, and `map` instead of raw arrays or custom containers.
- C++ Standard Library algorithms instead of manually coded ones.

Modern C++ adds

- **Language Features:**
  - Auto type deduction, smart pointers
  - rvalue references, lambdas
- **Default support for smart Idioms:**
  - Move Semantics, RAII
- **Standard Library Modules:**
  - Algorithms, Filesystem, Concurrency, Regex

New language feature: Keyword Auto

Keyword Auto

- auto used as a type specifier.
- The compiler deduces the type.
- Types remain static. Cannot assign to a different type without a cast.
- Zero runtime overhead.

Keyword Auto

```
auto a  = 1 + 2;                  // type is int
auto f  = 1.1;                    // float 32
auto d  = double {1.1};           // double 64
auto d2 = 3.14d;                  // double 64 using type suffix
auto c  = ‘c’;                    // const char
auto s  = std::string{ “Hello World!” };   // std::string
auto s2 = “Hello World”s;   // std::string
```

Keyword Auto

```
// C++98
map<int,string>::iterator i = m.begin();
double const xlimit = config["xlimit"];
singleton& s = singleton::instance();


// C++11
auto i = begin(m);
auto const xlimit = config["xlimit"];
auto& s = singleton::instance();
```

Auto enables the range-for loop

```
//C++98
for(auto i=begin(c); i!=end(c); ++i){
    use(*i);
}

//C++11
for(auto& e : c){
    use(e);
}
```

C++17 adds structured bindings

```
// C++11/14

tuple<int, string> func();

auto tup = func();

int i = get<0>(tup);
string s = get<1>(tup);

use(s, ++i);
```

```
// C++17

tuple<int, string> func();

auto [ i, s ] = func();

use(s, ++i)
```

Reasons to use Auto

- **Consistency**
  - Always uses the correct type, even when refactoring
- **Performance**
  - Never narrows on implicit casts
- **Safety**
  - Type mismatches are impossible
- **Convenience**
  - Some types are long or hard to type
  - Some types are only known by the compiler

New language feature: Smart Pointers

Why Smart Pointers?

- **Raw pointers and references are dangerous when used for object lifetime and ownership.**
  - Use after free
  - Double delete
  - Memory leak
- **But raw pointers and references are great for non-owning operations.**

Smart Pointers

- unique_ptr<T>
- shared_ptr<T>

Smart Pointers

- **Not auto_ptr**
- **Never auto_ptr**
- **Deprecated in C++11**
- **Removed in C++17**

Smart Pointers

- `unique_ptr<T>`
  - Default choice when creating objects.
  - Owns and manages another object through a pointer and disposes of that object when the `unique_ptr` goes out of scope.
  - Programmer does not worry about deleting. RAII
  - Cannot be copied, it’s unique.

```
auto p = make_unique<T>();
```

Smart Pointers

- **shared_ptr<T>**
  - Use only for objects shared by multiple scopes.
  - Several `shared_ptr` objects may own the same object.
  - The object is destroyed and its memory deallocated when the last remaining `shared_ptr` owning the object is destroyed.
  - Reference counted pointer.

```
auto p = make_shared<T>;
```

Reasons to use Smart Pointers

- unique_ptr creation and use in scope has zero overhead over raw pointers.
- Avoids many common pitfalls of pointer based ownership.
- shared_ptr ensures safe use of a pointer owned by many actors, at a modest cost.

When not to use shared pointers

- **Don't bother when the operation isn't owning**
  - Example: Function parameters
    - Prefer `const T&` for performance
- **Only use `shared_ptr` when needed**
  - Reference counting across scope is expensive

New language features:
`rvalue` references
move semantics

Motivating example

- Code up a function that performs a costly analysis and produces a large object.
- In Python there's essentially one option:

```
def make_big_vector(...)

result = make_big_vector()
```

- C++ has more control than that!

Motivating example

C++98:

- `//option 1: return by value: high cost to copy vector`
  ```
  vector<int> make_big_vector();
  vector<int> result = make_big_vector();
  ```
- `//option 2: return by pointer: no copy, remember to delete`
  ```
  vector<int>* make_big_vector();
  vector<int>* result = make_big_vector();
  ```
- `//option 3: pass by reference: no copy, but caller needs a named object`
  ```
  void make_big_vector( vector<int>& out );
  vector<int> result;
  make_big_vector( result );
  ```

Motivating Example

- C++11 makes option 1 fast, safe and efficient.

```
vector<int> make_big_vector();
auto result = make_big_vector();
```

- **Guaranteed not to copy the vector**
  - As efficient as options 2, 3
- **Type must have a move constructor**
  - Often provided by the compiler by default
  - Can be user defined, takes rvalue reference
  - Called “Move Semantics”

What is an `rvalue`?

It’s all about assignment

First approximation, good for intuition:
left side of assignment [=] right side of assignment

lvalue = rvalue

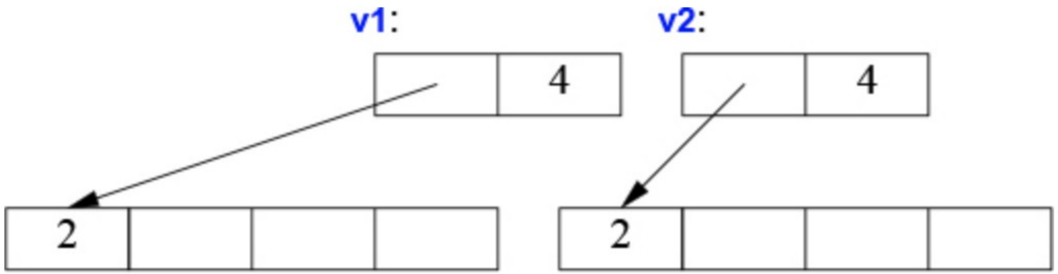
lvalue <-- rvalue

What is an `rvalue` really?

- **An `lvalue` is a location with an address that can hold an `rvalue`.**
- **An `rvalue` is what will go in the address:**
  - the number stored in int
  - a string literal in source code
  - the return value of a function

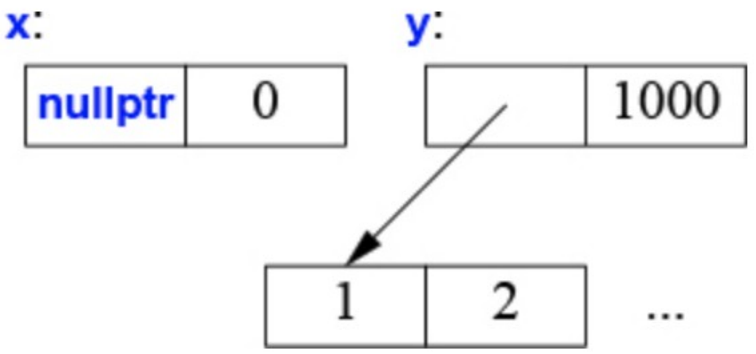
C++98 version of option 1

```
vector<int> make_big_vector(){
    vector<int> v1 = std::vector<int>(4);
    return v1;              // <-I’m an rvalue
};
auto v2 = make_big_vector();
```



C++11 version of option 1

```
vector<int> make_big_vector(){
    vector<int> x = std::vector<int>(1000);
    return x;           // <-I'm an rvalue
};
auto y = make_big_vector();
```



Move Operations

- ```
  class Vector {
      // ...
      Vector(Vector&& a):               // move constructor
          elem = a.elem,
          size = a.size
      {
          a.elem = nullptr;
          a.size = 0;
      }
      Vector& operator=(Vector&& a); // move assignment
  };
  ```
- && mean “rvalue reference”, not logical AND.
- Move operations “move” the contents of one object into another and make the source object ready for cleanup.
  ```

New language feature: lambda functions

Lambdas

- C++98 has function objects (aka functors).
- C++11 adds syntactic sugar for building function objects: lambdas
- Lambdas will frequently change the way you write code to make it more elegant and faster.
- Lambdas make the existing STL algorithms roughly 100x more usable.
- Newer C++ libraries increasingly are designed assuming lambdas as available, some even require you to write lambdas to use the library at all

What’s a lambda / function object?

- **C++ version of closure**
- **function + “environment”**
  - collection of variables in shared scope
- **Very similar to a class object**
  - Easier to write
  - Often smaller

C++98 function objects

```
int outer_scope_int = 42;

class GreaterThan42 {
    int i = outer_scope_int;
    bool operator()(int x){ return x>i; }
}

std::cout << GreaterThan42(7);
```

C++11 Lambdas

```
int i = 42;

auto GreaterThan42 =
     [=](int x){ return x>i; };

std::cout << GreaterThan42(7);
```

Lambda breakdown

- **`[](){} //Basic Lambda`**
- **`[]    //Capture list`**
  - How to store variables from the outer scope? Store by value or reference?
  - `[=]` Store everything by value
  - `[&]` Store everything by reference
  - `[&x, =y]` Store x by reference and y by value

Lambda breakdown

- **`[](){}` //Basic Lambda**
- **`()` // Parameter list**
  - Just a function parameter list
- **`{}` // Lambda Body**
  - Just a function body
  - Can have multiple statements

Standard Library: <algorithm>

std::algorithms

- https://en.cppreference.com/w/cpp/algorithm
- The algorithms library defines functions for a variety of purposes that operate on ranges of elements.
  - searching
  - sorting
  - counting
  - manipulating
- Note that a range is defined as [first, last) over an arbitrary container.
- Pre-date C++11. Defined for functors.
- Lambdas make them easier to use.

Lambdas and std::algorithms

```
// C++98
vector<int>::iterator i = v.begin();
// because we need to use i later

for( ; i != v.end(); ++i ) {
    if( *i > x && *i < y ) break;
}

// C++11
auto i = find_if( begin(v), end(v),
                  [=](int i){ return i>x && i<y; }
                  );
```

Some std::algorithms

- `find_if`: iterator to element which satisfies predicate function
- `for_each`: apply functor to every element
- `stable_sort`: sorts while preserving order between equal elements
- `binary_search`: determines if an element exists in a certain range

More std::algorithms

- https://en.cppreference.com/w/cpp/algorithm
- https://www.fluentcpp.com/2017/01/05/the-importance-of-knowing-stl-algorithms/
- https://channel9.msdn.com/Events/GoingNative/2013/Cpp-Seasoning
- https://www.fluentcpp.com/2018/07/10/105-stl-algorithms-in-less-than-an-hour/

World map of C++ STL Algorithms

Standard Library: <filesystem>

<filesystem>

- **Provides facilities for performing operations on file systems and their components**
  - paths
  - regular files
  - file_status and file_type
  - directories

<filesystem>

```
path f = "dir/hypothetical.cpp"; // naming a
file

assert(std::exists(f));          // f must exist?

if (std::is_regular_file(f)){   // f is file?
    std::cout << f
        << " is a file; its size is "
        << file_size(f)
        << '\n';
}
```

Standard Library <regex>

<regex>

- The regular expressions library provides a class that represents regular expressions.
- C++ supports multiple variants of regex.
- The regular expression syntax and semantics are designed so that regular expressions can be compiled into state machines for efficient execution.
- The regex type performs this compilation at run time.

<regex>

```
bool is_valid_ZIP(const string& s){

    regex pat {
        R"(\w{2}\s*\d{5}(-\d{4})?)"
    };

    return regex_match(s,pat);
}
```

Standard Library <thread>

<thread>

- **C++11 now includes built-in support for:**
  - threads
  - mutual exclusion
  - condition variables
  - futures.
- **C++20 is working on improving this with higher level abstractions**
- **Some <algorithms> are already parallelized**

<thread>

```
auto p = make_shared<T>();
auto thr = [](std::shared_ptr<T> p){...;};

std::thread t1(thr, p), t2(thr, p), t3(thr, p);

p.reset();   // release ownership

t1.join(); t2.join(); t3.join();

std::cout << “All threads completed, “;
          << “the last one deleted the T”;
```

The Future of C++:
C++20

Concepts

- **Template types are currently defined for all types**
- **Concepts limit the scope of permissible types**
  - Sequence Types
  - Arithmetic Types
  - Iterator Types ...

Concepts

- `template<typename T>`
  - \forall T such that T is a type
- `template<Sequence S, Number N>`
  - \forall S, N such that S is a Sequence and N is a Number

Concepts

```
//C++17
template<typename Seq, typename Num>
Num sum(Seq s, Num v){
     for (const auto& x : s)
           v+=x;
     return v;
}

//C++20
template<Sequence Seq, Number Num>
Num sum(Seq s, Num v){
     for (const auto& x : s)
           v+=x;
     return v;
}
```

Modules

- `#include "header.h"` is old and error-prone
- `#include` is expensive. Must re-parse headers each time they're included even if the code is already compiled and understood.
- The Modules extension add an `import` keyword which will import a module.

Modules

- A module library is compiled once, `imported` everywhere.
- Two modules can be imported in either order without changing their meaning.
- If you import something into a module, users of your module do not implicitly gain access to (and are not bothered by) what you imported: `import` is not transitive.
- Improves maintainability and compile-time performance.

Define a Module

```
// file Vector.cpp:
module;  // this compilation will define a module

export module Vector;  // defining the module
export class Vector {
    // Vector Declaration
};
Vector::Vector(int s):elem{new double[s]}, sz{s}{}
double& Vector::operator[](int i){return elem[i];}
int Vector::size(){return sz;}
export int size(const Vector& v) {return v.size();}
```

- This defines a module called Vector, exports the class Vector, all its member functions, and the non-member function size().

Use a Module

```
// file user.cpp:
import Vector;          // get Vector's interface
#include <cmath>        // get the standard math lib
double sqrt_sum(Vector& v){
     double sum = 0;
     for (int i=0; i!=v.size(); ++i)
           sum+=std::sqrt(v[i]);
     return sum;
}
```

Ranges

- Current `<algorithm>`s are defined on half open ranges using begin and end iterators.
- The Range proposal accepted into C++20 would add a `range` type to the standard.
- Rewrite `<algorithm>`s using just the range of a container.
- No more iterators `begin(v), end(v)`