BARTŁOMIEJ FILIPEK

C++17 IN DETAIL

LEARN THE EXCITING FEATURES OF
THE NEW C++ STANDARD!

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Learn the Exciting Features of The New C++ Standard!

Bartłomiej Filipek

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for Wiola and Mikołaj

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About the Author

Bartłomiej Filipek is a C++ software developer with more than 11 years of professional experience. In 2010 he graduated from Jagiellonian University in Cracow with a Masters Degree in Computer Science.

Bartek currently works at Xara, where he develops features for advanced document editors. He also has experience with desktop graphics applications, game development, large-scale systems for aviation, writing graphics drivers and even biofeedback. In the past, Bartek has also taught programming (mostly game and graphics programming courses) at local universities in Cracow.

Since 2011 Bartek has been regularly blogging at his website: bfilipek.com. In the early days the topics revolved around graphics programming, and now the blog focuses on Core C++. He also helps as co-organizer at C++ User Group in Krakow. You can hear Bartek in one @CppCast episode where he talks about C++17, blogging and text processing.

Since October 2018, Bartek has been a C++ Expert for Polish National Body that works directly with ISO/IEC JTC 1/SC 22 (C++ Standard Committee). In the same month, Bartek was also awarded by Microsoft and got his first MVP title for years 2019/2020.

In his spare time, he loves assembling trains and Lego with his little son. And he's a collector of large Lego models.

Preface

After the long awaited C++11, the C++ Committee has made changes to the standardisation process and we can now expect a new language standard every three years. In 2014 the ISO Committee delivered C++14. Now it's time for C++17, which was published at the end of 2017. As I am writing these words, in the middle of 2018, we're in the process of preparing C++20.

As you can see, the language and the Standard Library evolves quite fast! Since 2011 you've got a set of new library modules and language features every three years. Thus staying up to date with the whole state of the language has become quite a challenging task, and this is why this book will help you.

The chapters of this book describe all the significant changes in C++17 and will give you the essential knowledge to stay at the edge of the latest features. What's more, each section contains lots of practical examples and also compiler-specific notes to give you a more comfortable start.

It's a pleasure for me to write about new and exciting things in the language and I hope you'll have fun discovering C++17 as well!

Best regards,

Bartek

About the Book

C++11 was a major update for the language. With all the modern features like lambdas, constexpr, variadic templates, threading, range based for loops, smart pointers and many more powerful elements, it was enormous progress for the language. Even now, in 2018, lots of teams struggle to modernise their projects to leverage all the modern features. Later there was a minor update - C++14, which improved some things from the previous standard and added a few smaller elements. With C++17 we got a lot of mixed emotions.

Although C++17 is not as big as C++11, it's larger than C++14. Everyone expected modules, co-routines, concepts and other powerful features, but it wasn't possible to prepare everything on time.

Is C++17 weak?

Far from it! And this book will show you why!

The book brings you exclusive content about C++17 and draws from the experience of many articles that have appeared on bfilipek.com. The chapters were rewritten from the ground-up and updated with the latest information. All of that equipped with lots of new examples and practical tips. Additionally, the book provides insight into the current implementation status, compiler support, performance issues and other relevant knowledge to boost your current projects.

Who This Book is For

This book is intended for all C++ developers who have at least basic experience with C++11/14.

The principal aim of the book is to make you equipped with practical knowledge about C++17. After reading the book, you'll be able to move past C++11 and leverage the latest C++ techniques in your day to day tasks.

Please don't worry if you're not an expert in C++11/14. The book will give you necessary background, so you'll get the information in a proper context.

Overall Structure of the Book

C++17 brings a lot of changes to the language and to the Standard Library. In this book, all the new features were categorised into a few segments, so that they are easier to comprehend.

As a result, the book has the following sections:

- Part One - C++17 Language features:
  - Fixes and Deprecation
  - Language Clarification
  - General Language Features
  - Templates
  - Attributes
- Part Two - C++17 The Standard Library:
  - std::optional
  - std::variant
  - std::any
  - std::string_view
  - String Operations
  - Filesystem
  - Parallel STL
  - Other Changes
- Part Three - More Examples and Use Cases
- Appendix A - Compiler Support
- Appendix B - Resources and Links

The **first part** - about the language features - is shorter and will give you a quick run over the most significant changes. You can read it in any order you like.

The **second part** - describes a set of new library types that were added to the Standard. The helper types create a potential new vocabulary for C++ code: like when you use `optional`, `any`, `variant` or `string_view`. And what's more, you have new powerful capabilities especially in the form of parallel algorithms and the standard filesystem. A lot of examples in this part will use many other features from C++17.

The **third part** - brings together all of the changes in the language and shows examples where a lot of new features are used alongside. You'll see discussions about refactoring, simplifying code with new template techniques or working with parallel STL and the filesystem. While the first and the second part can also be used as a reference, the third part shows more of larger C++17 patterns that join many features.

A considerable advantage of the book is the fact that with each new feature you'll get information about the compiler support and the current implementation status. That way you'll be able to check if a particular version of the most popular compilers (MSVC, GCC or Clang) implements it or not. The book also gives practical hints on how to apply new techniques in your current codebase.

Reader Feedback

If you spot an error, typo, a grammar mistake... or anything else (especially some logical issues!) that should be corrected, then please let us know!

Write your feedback to bartlomiej.filipek AT bfilipek.com.

Example Code

You can find the ZIP package with all the example on the book's website: cppindetail.com/data/cpp17indetail.zip[1]. The same ZIP package should be also attached with the ebook.

A lot of the examples in the book are relatively short. You can copy and paste the lines into your favourite compiler/IDE and then run the code snippet.

Code License

The code for the book is available under the Creative Commons License.

Compiling

To use C++17 make sure you provide a proper flag for your compiler:

- in GCC (at least 7.1 or 8.0 or newer): use `-std=c++17` or `-std=c++2a`
- in Clang (at least 4.0 or newer): use `-std=c++17` or `-std=c++2a`
- in MSVC (Visual Studio 2017 or newer): use `/std:c++17` or `/std:c++latest` in `project options -> C/C++ -> Language -> C++ Language Standard`.

Formatting

The code is presented in a monospace font, similarly to the following example:

[1] https://www.cppindetail.com/data/cpp17indetail.zip

```cpp
// Chapter Example/example_one.cpp
#include <iostream>

int main()
{
    std::cout << "Hello World\n";
}
```

Snippets of longer programs were usually shortened to present only the core mechanics. In that case, you'll find their full version in the separate ZIP package that comes with the book.

The corresponding file for the code snippet is mentioned in the first line - for example, "`// Chapter Example/example_one.cpp`".

Usually, source code uses full type names with namespaces, like `std::string`, `std::filesystem::*`. However, to make code compact and present it nicely on a book page the namespaces sometimes might be removed, so they don't use space. Also, to avoid line wrapping longer lines might be manually split into two. In some case the code in the book might skip `include` statements.

Syntax Highlighting Limitations

The current version of the book might show some limitations regarding syntax highlighting.

For example:

- `if constexpr` - Link to Pygments issue: #1432 - C++ if constexpr not recognized (C++17)[2]
- The first menthod of a class is not highlighted - #1084 - First method of class not highlighted in C++[3]
- Teplate method is not highlighted #1434 - C++ lexer doesn't recognize function if return type is templated[4]
- Modern C++ attributes are sometimes not recognised properly

Other issues for C++ and Pygments: issues C++[5].

Online Compilers

Instead of creating local projects you can also leverage some online compilers. They offer a basic text editor and usually allow you to compile only one source file (the code that you edit). They are very handy if you want to play with a simple code example.

For example, many of the the code samples for this book were created in Coliru Online compiler and then adapted adequately for the book content.

Here's a list of some of the useful services:

[2] https://bitbucket.org/birkenfeld/pygments-main/issues/1432/c-if-constexpr-not-recognized-c-17
[3] https://bitbucket.org/birkenfeld/pygments-main/issues/1084/first-method-of-class-not-highlighted-in-c
[4] https://bitbucket.org/birkenfeld/pygments-main/issues/1434/c-lexer-doesnt-recognize-function-if
[5] https://bitbucket.org/birkenfeld/pygments-main/issues?q=c%2B%2B

- Coliru[6] - uses GCC 8.1.0 (as of July 2018), offers link sharing and a basic text editor, it's simple but very effective.
- Wandbox[7] - it offers a lot of compilers - for example, most of Clang and GCC versions - and also you can use boost libraries. Also offers link sharing.
- Compiler Explorer[8] - shows the compiler output from your code! Has many compilers to pick from.
- CppBench[9] - run a simple C++ performance tests (using google benchmark library).
- C++ Insights[10] - it's a Clang-based tool which does a source to source transformation. It shows how the compiler sees the code, for example by expanding lambdas, auto, structured bindings or range-based for loops.

There's also a nice list of online compilers gathered on this website: List of Online C++ Compilers[11].

[6] http://coliru.stacked-crooked.com/
[7] https://wandbox.org/
[8] https://gcc.godbolt.org/
[9] http://quick-bench.com/
[10] https://cppinsights.io/
[11] https://arnemertz.github.io/online-compilers/

1. General Language Features

Having finished the chapters on language fixes and clarifications, we're now ready to look at widespread features. Improvements described in this section also have the potential to make your code more compact and expressive.

For example, with Structured bindings, you can leverage much easier syntax tuples (and tuple-like expressions). Something that was easy in other languages like Python is also possible with good-old C++!

In this chapter you'll learn:

- Structured bindings/Decomposition declarations
- How to provide Structured Binding interface for your custom classes
- Init-statement for if/switch
- Inline variables and their impact on header-only libraries
- Lambda expressions that might be used in a `constexpr` context
- Simplified use of nested namespaces

Structured Binding Declarations

Do you often work with tuples or pairs?

If not, then you should probably start looking into those handy types. Not only are tuples (or pairs) suggested for returning multiple values from a function, but they've also got dedicated language support, making code easier and cleaner to write.

If you have a function that returns a few results:

```
std::pair<int, bool> InsertElement(int el) { ... }
```

You can use `auto ret = InsertElement(...)` and then refer to `ret.first` or `ret.second`. Alternatively you can leverage `std::tie` which will unpack the tuple/pair into custom variables:

```
int index { 0 };
bool flag { false };
std::tie(index, flag) = InsertElement(10);
```

Such code might be useful when you work with `std::set::insert` which returns `std::pair`:

```
std::set<int> mySet;
std::set<int>::iterator iter;
bool inserted;

std::tie(iter, inserted) = mySet.insert(10);

if (inserted)
    std::cout << "Value was inserted\n";
```

With C++17 the code can be more compact:

```
std::set<int> mySet;

auto [iter, inserted] = mySet.insert(10);
```

Now, instead of `pair.first` and `pair.second` you can use variables with more concrete names.

And, also you have one line instead of three and the code is easier to read and safer.

The Syntax

This part might be updated to become clearer

The basic syntax is as follows:

```
auto [a, b, c, ...] = expression;
auto [a, b, c, ...] { expression };
auto [a, b, c, ...] ( expression );
```

The compiler introduces all identifiers from the `a, b, c, ...` list as names in the surrounding scope and binds them to sub-objects or elements of the object denoted by expression.

Behind the scenes, the compiler might generate the following **pseudo code**:

```
auto tempTuple = expression;
using a = tempTuple.first;
using b = tempTuple.second;
using c = tempTuple.third;
```

Conceptually, the expression is copied into a tuple-like object with member variables that are exposed through `a`, `b` and `c`. However, the variables `a`, `b` and `c` are not references, they are aliases (or bindings) to the hidden object member variables.

For example:

```
std::pair a(0, 1.0f);
auto [x, y] = a;
```

`x` binds to `int` stored in the hidden object that is a copy of `a`. And similarly, `y` binds to `float`.

Modifiers

Several modifiers can be used with structured bindings:

`const` modifiers:

```
const auto [a, b, c, ...] = expression;
```

References:

```
auto& [a, b, c, ...] = expression;
auto&& [a, b, c, ...] = expression;
```

For example:

```
std::pair a(0, 1.0f);
auto& [x, y] = a;
x = 10;  // write access
// a.first is now 10
```

In the above example `x` binds to the element in the hidden object that is a reference to `a`.

You can also add `[[attribute]]`:

```
[[maybe_unused]] auto& [a, b, c, ...] = expression;
```

Structured Bindings or Decomposition Declaration?

For this feature, you might have seen another name "decomposition declaration" in use. During the standardisation process those two names were considered, but now the final version sticks with "Structured Bindings."

Binding

Structured Binding is not only limited to tuples, we have three cases from which we can bind from:

1. If the initializer is an array:

```
// works with arrays:
double myArray[3] = { 1.0, 2.0, 3.0 };
auto [a, b, c] = myArray;
```

2. If the initializer supports `std::tuple_size<>` and provides `get<N>()` and `std::tuple_element` functions:

```
auto [a, b] = myPair; // binds myPair.first/second
```

In other words, you can provide support for your classes, assuming you add `get<N>` interface implementation. See an example in the later section.

3. If the initializer's type contains only non static, public members:

```
struct S { int x1 : 2; volatile double y1; };
S f();
const auto [ x, y ] = f();
```

Now it's also quite easy to get a reference to a tuple member:

```
auto& [ refA, refB, refC, refD ] = myTuple;
```

Note: In C++17, you could use structured bindings to bind to class members as long as they were public. This might be a problem when you want to access private members in the implementation of the class. With C++20 it should be fixed. See P0969R0[1].

Example

One of the **coolest use cases** - binding inside a range based for loop:

```
std::map<KeyType, ValueType> myMap;
for (const auto & [key,val] : myMap)
{
    // use key/value rather than iter.first/iter.second
}
```

In the above example, we bind to a pair of `[key, val]` so we can use those names in the loop. Before C++17 you had to operate on an iterator from the map - which is a pair `<first, second>`. Using the real names `key/value` is more expressive than the pair.

The above technique can be used in:

```
#include <map>
#include <iostream>
#include <string>

int main()
{
    const std::map<std::string, int> mapCityPopulation {
        { "Beijing", 21'707'000 },
        { "London", 8'787'892 },
        { "New York", 8'622'698 }
    };
```

[1] https://wg21.link/P0969R0

```
    for (auto&[city, population] : mapCityPopulation)
        std::cout << city << ": " << population << '\n';
}
```

In the loop body, you can safely use `city` and `population` variables.

Providing Structured Binding Interface for Custom Class

As mentioned earlier you can provide Structured Binding support for a custom class.

To do that you have to define `get<N>`, `std::tuple_size` and `std::tuple_element` specialisations for your type.

For example, if you have a class with three members, but you'd like to expose only its public interface:

```
class UserEntry {
public:
    void Load() { }

    std::string GetName() const { return name; }
    unsigned GetAge() const { return age; }
private:
    std::string name;
    unsigned age { 0 };
    size_t cacheEntry { 0 }; // not exposed
};
```

The interface for Structured Bindings:

```
// with if constexpr:
template <size_t I> auto get(const UserEntry& u) {
    if constexpr (I == 0) return u.GetName();
    else if constexpr (I == 1) return u.GetAge();
}

namespace std {
    template <> struct tuple_size<UserEntry> : std::integral_constant<size_t, 2> { };

    template <> struct tuple_element<0,UserEntry> { using type = std::string; };
    template <> struct tuple_element<1,UserEntry> { using type = unsigned; };
}
```

`tuple_size` specifies how many fields are available, `tuple_element` defines the type for a specific element and `get<N>` returns the values.

Alternatively, you can also use explicit `get<>` specialisations rather than `if constexpr`:

```
template<> string get<0>(const UserEntry &u)  { return u.GetName(); }
template<> unsigned get<1>(const UserEntry &u) { return u.GetAge(); }
```

For a lot of types, writing two (or several) functions might be simpler than using `if constexpr`.

Now you can use `UserEntry` in a structured binding, for example:

```
UserEntry u;
u.Load();
auto [name, age] = u; // read access
std:: cout << name << ", " << age << '\n';
```

This example only allows read access of the class. If you want write access, then the class should also provide accessors that return references to members. Later you have to implement `get` with references support.

As you've seen `if constexpr` was used to implement `get<N>` functions, read more in the `if constexpr` chapter.

Extra Info

The change was proposed in: P0217[2](wording), P0144[3](reasoning and examples), P0615[4](renaming "decomposition declaration" with "structured binding declaration").

[2] https://wg21.link/p0217
[3] https://wg21.link/p0144
[4] https://wg21.link/p0615

Init Statement for `if` and `switch`

C++17 provides new versions of the if and switch statements:

`if (init; condition)` and `switch (init; condition)`.

In the `init` section you can specify a new variable and then check it in the `condition` section. The variable is visible only in `if`/`else` scope.

To achieve a similar result, before C++17 you had to write:

```
{
    auto val = GetValue();
    if (condition(val))
        // on success
    else
        // on false...
}
```

Look, that `val` has a separate scope, without that it 'leaks' to enclosing scope.

Now, in C++17, you can write:

```
if (auto val = GetValue(); condition(val))
    // on success
else
    // on false...
```

Notice that `val` is visible only inside the `if` and `else` statements, so it doesn't 'leak.' `condition` might be any boolean condition.

Why is this useful?

Let's say you want to search for a few things in a string:

```
const std::string myString = "My Hello World Wow";

const auto pos = myString.find("Hello");
if (pos != std::string::npos)
    std::cout << pos << " Hello\n"

const auto pos2 = myString.find("World");
if (pos2 != std::string::npos)
    std::cout << pos2 << " World\n"
```

You have to use different names for pos or enclose it with a separate scope:

```
{
    const auto pos = myString.find("Hello");
    if (pos != std::string::npos)
        std::cout << pos << " Hello\n"
}

{
    const auto pos = myString.find("World");
    if (pos != std::string::npos)
        std::cout << pos << " World\n"
}
```

The new if statement will make that additional scope in one line:

```
if (const auto pos = myString.find("Hello"); pos != std::string::npos)
    std::cout << pos << " Hello\n";

if (const auto pos = myString.find("World"); pos != std::string::npos)
    std::cout << pos << " World\n";
```

As mentioned before, the variable defined in the if statement is also visible in the `else` block. So you can write:

```
if (const auto pos = myString.find("World"); pos != std::string::npos)
    std::cout << pos << " World\n";
else
    std::cout << pos << " not found!!\n";
```

Plus, you can use it with structured bindings (following Herb Sutter code[5]):

```
// better together: structured bindings + if initializer
if (auto [iter, succeeded] = mymap.insert(value); succeeded) {
    use(iter);  // ok
    // ...
} // iter and succeeded are destroyed here
```

Extra Info

The change was proposed in: P0305R1[6].

[5] https://herbsutter.com/2016/06/30/trip-report-summer-iso-c-standards-meeting-oulu/
[6] http://wg21.link/p0305r1

Inline Variables

With Non-Static Data Member Initialisation introduced in C++11, you can now declare and initialise member variables in one place:

```
class User
{
    int _age {0};
    std::string _name {"unknown"};
};
```

Still, with static variables (or `const static`) you usually need to define it in some `cpp` file.

C++11 and `constexpr` keyword allow you to declare and define static variables in one place, but it's limited to constant expressions only.

Previously, only methods/functions could be specified as `inline`, but now you can do the same with variables, inside a header file.

> **From the proposal P0386R2**[7]: A variable declared inline has the same semantics as a function declared inline: it can be defined, identically, in multiple translation units, must be defined in every translation unit in which it is used, and the behaviour of the program is as if there was exactly one variable.

For example:

```
// inside a header file:
struct MyClass
{
    static const int sValue;
};

// later in the same header file:
inline int const MyClass::sValue = 777;
```

Or even declaration and definition in one place:

[7] http://wg21.link/p0386r2

```
struct MyClass
{
    inline static const int sValue = 777;
};
```

Also, note that `constexpr` variables are `inline` implicitly, so there's no need to use `constexpr inline myVar = 10;`.

An `inline` variable is also more flexible than a `constexpr` variable as it doesn't have to be initialised with a constant expression. For example, you can initialise an `inline` variable with `rand()`, but it's not possible to do the same with `constexpr` variable.

How Can it Simplify the Code?

A lot of header-only libraries can limit the number of hacks (like using inline functions or templates) and switch to using inline variables.

For example:

```
class MyClass
{
    static inline int Seed(); // static method
};

inline int MyClass::Seed() {
    static const int seed = rand();
    return seed;
}
```

Can be changed into:

```
class MyClass
{
    static inline int seed = rand();
};
```

C++17 guarantees that `MyClass::seed` will have the same value (generated at runtime) across all the compilation units!

Extra Info

The change was proposed in: P0386R2[8].

[8] http://wg21.link/p0386r2

`constexpr` Lambda Expressions

Lambda expressions were introduced in C++11, and since that moment they've become an essential part of modern C++. Another significant feature of C++11 is "constant expressions" - declared mainly with `constexpr`. In C++17 the two elements are allowed to exist together - so your lambda can be invoked in a constant expression context.

In C++11/14 the following code wouldn't compile:

```
auto SimpleLambda = [] (int n)  { return n; };
static_assert(SimpleLambda(3) == 3, "");
```

GCC compiled with the `-std=c++11` flag reports the following error:

```
error: call to non-'constexpr' function 'main()::<lambda(int)>'
     static_assert(SimpleLambda(3) == 3, "");
```

However, with the `-std=c++17` the code compiles! This is because since C++17 lambda expressions that follow the rules of standard `constexpr` functions are implicitly declared as `constexpr`.

What does that mean? What are the limitations?

Quoting the Standard - *10.1.5 The constexpr specifier [dcl.constexpr]*

> The definition of a constexpr function shall satisfy the following requirements:
>
> - it shall not be virtual (13.3);
> - its return type shall be a literal type; A >- each of its parameter types shall be a literal type; A >- its function-body shall be = delete, = default, or a compound-statement that does not contain:
>   - an asm-definition,
>   - a goto statement,
>   - an identifier label (9.1),
>   - a try-block, or
>   - a definition of a variable of non-literal type or of static or thread storage duration or for which no initialisation is performed.

Practically, if you want your function or lambda to be executed at compile-time then the body of this function shouldn't invoke any code that is not `constexpr`. For example, you cannot allocate memory dynamically.

Lambda can be also explicitly declared `constexpr`:

```
auto SimpleLambda = [] (int n) constexpr { return n; };
```

And if you violate the rules of `constexpr` functions, you'll get a compile-time error.

```
auto FaultyLeakyLambda = [] (int n) constexpr {
    int *p = new int(10);

    return n + (*p);
};
```

`operator new` is not `constexpr` so that won't compile.

Having `constexpr` lambdas will be a great feature combined with the `constexpr` standard algorithms that are coming in C++20.

Extra Info

The change was proposed in: P0170[9].

[9] http://wg21.link/p0170

Nested Namespaces

Namespaces allow grouping types and functions into separate logical units.

For example, it's common to see that each type or function from a library XY will be stored in a namespace `xy`. Like in the below case, where there's `SuperCompressionLib` and it exposes functions called `Compress()` and `Decompress()`:

```
namespace SuperCompressionLib {
    bool Compress();
    bool Decompress();
}
```

Things get interesting if you have two or more nested namespaces.

```
namespace MySuperCompany {
    namespace SecretProject {
        namespace SafetySystem {
            class SuperArmor {
                // ...
            };
            class SuperShield {
                // ...
            };
        } // SafetySystem
    } // SecretProject
} // MySuperCompany
```

With C++17 nested namespaces can be written in a more compact way:

```
namespace MySuperCompany::SecretProject::SafetySystem {
    class SuperArmor {
    // ...
    };
    class SuperShield {
    // ...
    };
}
```

Such syntax is comfortable, and it will be easier to use for developers that have experience in languages like C# or Java.

In C++17 also the Standard Library was “compacted” in several places by using the new nested namespace feature:

For example for `regex`.

In C++17 it’s defined as:

```
namespace std::regex_constants {
    typedef T1 syntax_option_type;
    // ...
}
```

Before C++17 the same was declared as:

```
namespace std {
    namespace regex_constants {
        typedef T1 syntax_option_type;
        // ...
    }
}
```

The above nested declarations appear in the C++ Specification, but it might look different in an STL implementation.

Extra Info

The change was proposed in: N4230[10].

Compiler support

Feature	GCC	Clang	MSVC
Structured Binding Declarations	7.0	4.0	VS 2017 15.3
Init-statement for if/switch	7.0	3.9	VS 2017 15.3
Inline variables	7.0	3.9	VS 2017 15.5
`constexpr` Lambda Expressions	7.0	5.0	VS 2017 15.3
Nested namespaces	6.0	3.6	VS 2015

[10] http://wg21.link/N4230

2. Standard Attributes

Code annotations - attributes - are probably not the best known feature of C++. However, they might be handy for expressing additional information for the compiler and also for other programmers. Since C++11 there has been a standard way of specifying attributes. And in C++17 you got even more useful additions related to attributes.

In this chapter you'll learn:

- What are the attributes in C++
- Vendor-specific code annotations vs the Standard form
- In what cases attributes are handy
- C++11 and C++14 attributes
- New additions in C++17

Why Do We Need Attributes?

Have you ever used `__declspec`, `__attribute` or `#pragma` directives in your code?

For example:

```
// set an alignment
struct S { short f[3]; } __attribute__ ((aligned (8)));

// this function won't return
void fatal () __attribute__ ((noreturn));
```

Or for DLL import/export in MSVC:

```
#if COMPILING_DLL
    #define DLLEXPORT __declspec(dllexport)
#else
    #define DLLEXPORT __declspec(dllimport)
#endif
```

Those are existing forms of compiler specific attributes/annotations.

So what is an attribute?

An attribute is additional information that can be used by the compiler to produce code. It might be utilised for optimisation or some specific code generation (like DLL stuff, OpenMP, etc.). In addition, annotations allow you to write more expressive syntax and help other developers to reason about code.

Contrary to other languages such as C#, in C++ that the compiler fixes meta information, you cannot add user-defined attributes. In C# you can 'derive' from `System.Attribute`.

What's best about Modern C++ attributes?

With the modern C++, we get more and more standardised attributes that will work with other compilers. So we're moving from compiler specific annotation to standard forms.

In the next section you'll see how attributes used to work before C++11.

Before C++11

Each compiler introduced its own set of annotations, usually with a different keyword.

Often, you could see code with `#pragma`, `_declspec`, `__attribute` spread throughout the code.

Here's the list of the common syntax from GCC/Clang and MSVC:

GCC Specific Attributes

GCC uses annotation in the form of `__attribute__((attr_name))`. For example:

```
int square (int) __attribute__ ((pure)); // pure function
```

Documentation:

- Attribute Syntax - Using the GNU Compiler Collection (GCC)[1]
- Using the GNU Compiler Collection (GCC): Common Function Attributes[2]

MSVC Specific Attributes

Microsoft mostly used `__declspec` keyword, as their syntax for various compiler extensions. See the documentation here: `__declspec` Microsoft Docs[3].

```
__declspec(deprecated) void LegacyCode() { }
```

Clang Specific Attributes

Clang, as it's straightforward to customise, can support different types of annotations, so look at the documentation to find more. Most of GCC attributes work with Clang.

See the documentation here: Attributes in Clang — Clang documentation[4].

Attributes in C++11 and C++14

C++11 took one big step to minimise the need to use vendor specific syntax. By introducing the standard format, we can move a lot of compiler-specific attributes into the universal set.

C++11 provides a nicer format of specifying annotations over our code.

The basic syntax is just `[[attr]]` or `[[namespace::attr]]`.

You can use `[[attr]]` over almost anything: types, functions, enums, etc., etc.

For example:

[1] https://gcc.gnu.org/onlinedocs/gcc-4.8.1/gcc/Attribute-Syntax.html
[2] https://gcc.gnu.org/onlinedocs/gcc/Common-Function-Attributes.html#Common-Function-Attributes
[3] https://docs.microsoft.com/en-Us/cpp/cpp/declspec
[4] https://clang.llvm.org/docs/AttributeReference.html

```
[[abc]] void foo()
{

}
```

In C++11 we have the following attributes:

`[[noreturn]]`:

A function does not return. The behaviour is undefined if the function with this attribute returns.

- for example `[[noreturn]] void terminate() noexcept;`
- functions like `std::abort` or `std::exit` are marked with this attribute.

`[[carries_dependency]]`:

Indicates that the dependency chain in release-consume `std::memory_order` propagates in and out of the function, which allows the compiler to skip unnecessary memory fence instructions. Mostly to help to optimise multi-threaded code and when using different memory models.

C++14 added:

`[[deprecated]]` and `[[deprecated("reason")]]`:

Code marked with this attribute will be reported by the compiler. You can set a "reason" why.

Example of `[[deprecated]]`:

```
[[deprecated("use AwesomeFunc instead")]] void GoodFunc() { }

// call somewhere:
GoodFunc();
```

GCC might report a warning:

```
warning: 'void GoodFunc()' is deprecated: use AwesomeFunc instead
[-Wdeprecated-declarations]
```

You know a bit about the old approach, new way in C++11/14... so what's the deal with C++17?

C++17 additions

With C++17 we get three more standard attributes:

- `[[fallthrough]]`
- `[[nodiscard]]`
- `[[maybe_unused]]`

Plus three supporting features.

Extra Info

The new attributes were specified in P0188[5] and P0068[6](reasoning).

Let's go through the new attributes first:

`[[fallthrough]]` attribute

Indicates that a fall-through in a switch statement is intentional and a warning should not be issued for it.

```
switch (c) {
case 'a':
    f(); // Warning! fallthrough is perhaps a programmer error
case 'b':
    g();
[[fallthrough]]; // Warning suppressed, fallthrough is ok
case 'c':
    h();
}
```

With this attribute, the compiler can understand the intentions of a programmer. And what's more, it's also much more readable than using a comment.

`[[maybe_unused]]` attribute

Suppresses compiler warnings about unused entities when they are declared with `[[maybe_unused]]`.

[5] https://wg21.link/p0188
[6] https://wg21.link/p0068

```
static void impl1() { ... } // Compilers may warn about this
[[maybe_unused]] static void impl2() { ... } // Warning suppressed


void foo() {
   int x = 42; // Compilers may warn about this
   [[maybe_unused]] int y = 42; // Warning suppressed
}
```

`[[nodiscard]]` attribute

`[[nodiscard]]` can be applied on a function or a type declaration to mark the importance of the returned value:

```
[[nodiscard]] int Compute();
void Test() {
    Compute(); // Warning! return value of a
               // nodiscard function is discarded
}
```

If you forget to assign the result to a variable, then the compiler should emit a warning.

What it means is that you can force users to handle errors. For example, what happens if you forget about using the return value from `new` or `std::async()`?

Additionally, the attribute can be applied on types. One use case for it might be error codes:

```
enum class [[nodiscard]] ErrorCode {
    OK,
    Fatal,
    System,
    FileIssue
};


ErrorCode OpenFile(std::string_view fileName);
ErrorCode SendEmail(std::string_view sendto,
                    std::string_view text);
ErrorCode SystemCall(std::string_view text);
```

Now every time you'd like to call such functions you're "forced" to check the return value. For important functions checking return codes might be crucial and using `[[nodiscard]]` might reduce a few bugs.

You might also ask what it means to 'use' a return value?

In the Standard, it's defined as `Discarded-value expressions`[7] so if your function is called only for side effects (there's no if statement around or assignment) the compiler is encouraged to report a warning.

However to suppress the warning you can explicitly cast the return value to `void` or use `[[maybe_unused]]`:

```
[[nodiscard]] int Compute();
void Test() {
    static_cast<void>(Compute()); // fine...

    [[maybe_unused]] auto ret = Compute();
}
```

In addition, in C++20 the Standard Library will apply`[[nodiscard]]` in a few places: `operator new`, `std::async()`, `std::allocate()`, `std::launder()`, and `std::empty()`.
This feature was already merged into C++20 with P0600R1[8].

Attributes for namespaces and enumerators

The idea for attributes in C++11 was to be able to apply them to all sensible places: like classes, functions, variables, typedefs, templates, enumerations... But there was an issue in the specification that blocked attributes when they were applied on namespaces or enumerators.

This is now fixed in C++17. We can now write:

```
namespace [[deprecated("use BetterUtils")]] GoodUtils {
    void DoStuff() { }
}
```

[7] http://en.cppreference.com/w/cpp/language/expressions#Discarded-value_expressions
[8] http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/p0600r1.pdf

```
namespace BetterUtils {
    void DoStuff() { }
}

int main()
{
    GoodUtils::DoStuff();
}
```

Clang reports:

```
warning: 'GoodUtils' is deprecated: use BetterUtils
[-Wdeprecated-declarations]
```

Another example is the use of deprecated attribute on enumerators:

```
enum class ColorModes
{
    RGB [[deprecated("use RGB8")]],
    RGBA [[deprecated("use RGBA8")]],
    RGBA16F,
    RGB8,
    RGBA8
};

// use:
auto colMode = ColorModes::RGBA;
```

Under GCC we'll get:

```
warning: 'RGBA' is deprecated: use RGBA8
[-Wdeprecated-declarations]
```

Extra Info

The change was described in N4266[9](wording) and N4196[10](reasoning).

[9] https://wg21.link/n4266
[10] https://wg21.link/n4196

Ignore unknown attributes

The feature is mostly for clarification.

Before C++17, if you tried to use some compiler specific attribute, you might even get an error when compiling in another compiler that doesn't support it. Now, the compiler omits the attribute specification and won't report anything (or just a warning). This wasn't mentioned in the standard, and it needed clarification.

```
// compilers which don't
// support MyCompilerSpecificNamespace will ignore this attribute
[[MyCompilerSpecificNamespace::do_special_thing]]
void foo();
```

For example in GCC 7.1 there's a warnings:

```
warning: 'MyCompilerSpecificNamespace::do_special_thing'
scoped attribute directive ignored [-Wattributes]
void foo();
```

Extra Info

The change was described in P0283R2[11](wording) and P0283R1[12](reasoning).

Using attribute namespaces without repetition

The feature simplifies the case where you want to use multiple attributes, like:

```
void f() {
    [[rpr::kernel, rpr::target(cpu,gpu)]] // repetition
    doTask();
}
```

Proposed change:

[11] https://wg21.link/p0283r2
[12] https://wg21.link/p0283r1

```
void f() {
    [[using rpr: kernel, target(cpu,gpu)]]
    doTask();
}
```

That simplification might help when building tools that automatically translate annotated code of that type into different programming models.

Extra Info

More details in: P0028R4[13].

Section Summary

All Attributes available in C++17:

- `[[noreturn]]`
- `[[carries_dependency]]`
- `[[deprecated]]`
- `[[deprecated("reason")]]`
- `[[fallthrough]]`
- `[[nodiscard]]`
- `[[maybe_unused]]`

Each compiler vendor can specify their own syntax and list of available attributes and extensions. In Modern C++ the committee tried to extract common parts for attributes. The target is to stick only to the Standard attributes, but that depends on your platform. For example, in the embedded environment there might be a lot of essential and platform-specific annotations that glue code and hardware together.

There's also quite an important quote from Bjarne Stroustrup's C++11 FAQ/Attributes[14]:

> There is a reasonable fear that attributes will be used to create language dialects. The recommendation is to use attributes to only control things that do not affect the meaning of a program but might help detect errors (e.g. `[[noreturn]]`) or help optimizers (e.g. `[[carries_dependency]]`).

[13] http://wg21.link/p0028r4
[14] http://stroustrup.com/C++11FAQ.html#attributes

Compiler support

Feature	GCC	Clang	MSVC
`[[fallthrough]]`	7.0	3.9	15.0
`[[nodiscard]]`	7.0	3.9	15.3
`[[maybe_unused]]`	7.0	3.9	15.3
Attributes for namespaces and enumerators	4.9/6[15]	3.4	14.0
Ignore unknown attributes	All versions	3.9	14.0
Using attribute namespaces without repetition	7.0	3.9	15.3

All of the above compilers also support C++11/14 attributes.

[15] GCC 4.9 (namespaces) / GCC 6 (enumerations)

3. String Conversions

`string_view` is not the only feature that we get in C++17 that relates to strings. While views can reduce the number of temporary copies, there's also another feature that is very handy: conversion utilities. In the new C++ Standard you have two set of functions `from_chars` and `to_chars` that are low level and promises impressive performance improvements.

In this chapter you'll learn:

- Why do we need low-level string conversion routines?
- Why the current options in the Standard Library might not be enough?
- How to use C++17's conversion routines
- What performance gains you can expect from the new routines

Elementary String Conversions

The growing number of data formats like JSON or XML requires efficient string processing and manipulation. The maximum performance is especially crucial when such formats are used to communicate over the network where high throughput is the key.

For example, you get the characters in a network packet, you deserialise it (convert strings into numbers), then process the data, and finally it's serialised back to the same file format (numbers into strings) and sent over the network as a response.

The Standard Library had bad luck in those areas, as it's usually perceived to be too slow for such advanced string processing. Often developers prefer custom solutions or third-party libraries.

The situation might change as with C++17 we get two sets of functions: `from_chars` and `to_chars` that allow for low-level string conversions.

The feature was introduced in P0067[1]

In the original paper there's a useful table that summarises all the current solutions:

facility	shortcomings
`sprintf`	format string, locale, buffer overrun
`snprintf`	format string, locale
`sscanf`	format string, locale
`atol`	locale, does not signal errors
`strtol`	locale, ignores whitespace and 0x prefix
`strstream`	locale, ignores whitespace
`stringstream`	locale, ignores whitespace, memory allocation
`num_put` / `num_get` facets	locale, virtual function
`to_string`	locale, memory allocation
`stoi` etc.	locale, memory allocation, ignores whitespace and 0x prefix, exceptions

As you can see above, sometimes converting functions do too much work, which makes the whole processing slower. Moreover, often there's no need for the extra features.

First of all, all of them use "locale". So even if you work with universal strings, you have to pay a little price for localisation support. For example, if you parse numbers from XML or JSON, there's no need to apply current system language, as those formats are interchangeable.

The next issue is error reporting. Some functions might throw an exception, some of them return just a basic value. Exceptions might not only be costly (as throwing might involve extra memory allocations) but often a parsing error is not an exceptional situation - usually, an application is prepared for such cases. Returning a simple value - for example, `0` for `atoi`, `0.0` for `atof` is also limited, as in that case you don't know if the parsing was successful or not.

Another problem, especially with older C-style API, is that you have to provide some form of the "format string". Parsing such string might involve some additional cost.

[1] https://wg21.link/P0067

Another thing is “empty space” support. Functions like `strtol` or `stringstream` might skip empty spaces at the beginning of the string. That might be handy, but sometimes you don’t want to pay for that extra feature.

There’s also another critical factor: safety. Simple functions don’t offer any buffer overrun solutions, and also they work only on null-terminated strings. In that case, you cannot use `string_view` to pass the data.

The new C++17 API addresses all of the above issues. Rather than providing many functionalities, they focus on giving the very low-level support. That way you can have the maximum speed and tailor them to your needs.

The new functions are guaranteed to be:

- non-throwing - in case of some error they won’t throw any exception (as `stoi`)
- non-allocating - the whole processing is done in place, without any extra memory allocation
- no locale support - the string is parsed universally as if used with default (“C”) locale
- memory safety - input and output range are specified to allow for buffer overrun checks
- no need to pass string formats of the numbers
- error reporting additional information about the conversion outcome

All in all, with C++17 you have two set of functions:

- `from_chars` - for conversion from strings into numbers, integer and floating points.
- `to_chars` - for converting numbers into string.

Let’s have a look at the functions in a bit more detail.

Converting From Characters to Numbers: `from_chars`

`from_chars` is a set of overloaded functions: for integral types and floating point types.

For integral types we have the following functions:

```
std::from_chars_result from_chars(const char* first,
                                  const char* last,
                                  TYPE &value,
                                  int base = 10);
```

Where `TYPE` expands to all available signed and unsigned integer types and `char`.

`base` can be a number ranging from 2 to 36.

Then there’s the floating point version:

```
std::from_chars_result from_chars(const char* first,
                    const char* last,
                    FLOAT_TYPE& value,
                    std::chars_format fmt = std::chars_format::general);
```

`FLOAT_TYPE` expands to `float`, `double` or `long double`.

`chars_format` is an enum with the following values:

```
enum class chars_format {
    scientific = /*unspecified*/,
    fixed = /*unspecified*/,
    hex = /*unspecified*/,
    general = fixed | scientific
};
```

It's a bit-mask type, that's why the values for enums are implementation specific. By default, the format is set to be `general` so the input string can use "normal" floating point format with scientific form as well.

The return value in all of those functions (for integers and floats) is `from_chars_result` :

```
struct from_chars_result {
    const char* ptr;
    std::errc ec;
};
```

`from_chars_result` holds valuable information about the conversion process.

Here's the summary:

- On **Success** `from_chars_result::ptr` points at the first character not matching the pattern, or has the value equal to `last` if all characters match and `from_chars_result::ec` is value-initialized.
- On **Invalid conversion** `from_chars_result::ptr` equals `first` and `from_chars_result::ec` equals `std::errc::invalid_argument`. `value` is unmodified.
- On **Out of range** - The number it too large to fit into the value type. `from_chars_result::ec` equals `std::errc::result_out_of_range` and `from_chars_result::ptr` points at the first character not matching the pattern. `value` is unmodified.

Examples

To sum up, here are two examples of how to convert a string into number using `from_chars`, to `int` and `float`.

Integral types

```
// Chapter String Conversions/from_chars_basic.cpp
#include <charconv> // from_char, to_char
#include <string>

int main()
{
    const std::string str { "12345678901234" };
    int value = 0;
    const auto res = std::from_chars(str.data(),
                                     str.data() + str.size(),
                                     value);

    if (res.ec == std::errc())
    {
        std::cout << "value: " << value
                  << ", distance: " << res.ptr - str.data() << '\n';
    }
    else if (res.ec == std::errc::invalid_argument)
    {
        std::cout << "invalid argument!\n";
    }
    else if (res.ec == std::errc::result_out_of_range)
    {
        std::cout << "out of range! res.ptr distance: "
                  << res.ptr - str.data() << '\n';
    }
}
```

The example is straightforward, it passes a string `str` into `from_chars` and then displays the result with additional information if possible.

Below you can find an output for various `str` value.

`str` value	**output**
`12345`	`value: 12345, distance 5`
`12345678901234`	`out of range! res.ptr distance: 14`
`hfhfyt`	`invalid argument!`

In the case of `12345678901234` the conversion routine could parse the number, but it's too large to fit in `int`.

Floating Point

To get the floating point test, we can replace the top lines of the previous example with:

```
// Chapter String Conversions/from_chars_basic_float.cpp

const std::string str { "16.78" };
double value = 0;
const auto format = std::chars_format::general;
const auto res = std::from_chars(str.data(),
                                 str.data() + str.size(),
                                 value,
                                 format);
```

Here's the example output that we get:

str value	**format** value	output
1.01	fixed	value: 1.01, distance 4
-67.90000	fixed	value: -67.9, distance: 9
1e+10	fixed	value: 1, distance: 1 - scientific notation not supported
1e+10	fixed	value: 1, distance: 1 - scientific notation not supported
20.9	scientific	invalid argument!, res.p distance: 0
20.9e+0	scientific	value: 20.9, distance: 7
-20.9e+1	scientific	value: -209, distance: 8
F.F	hex	value: 15.9375, distance: 3
-10.1	hex	value: -16.0625, distance: 5

The `general` format is a combination of `fixed` and `scientific` so it handles regular floating point string with the additional support for `e+num` syntax.

You have a basic understanding about converting from strings to numbers, so let's have a look at how to do the opposite way.

Parsing a Command Line

In the `std::variant` chapter there's an example with parsing a command line parameters. The example uses `from_chars` to match the best type: `int`, `float` or `std::string` and then stores it in a `std::variant`.

You can find the example here: Parsing a Command Line, the Variant Chapter

Converting Numbers into Characters: `to_chars`

`to_chars` is a set of overloaded functions for integral and floating point types.

For integral types there's one declaration:

```
std::to_chars_result to_chars(char* first, char* last,
                              TYPE value, int base = 10);
```

Where `TYPE` expands to all available signed and unsigned integer types and `char`.

Since `base` might range from 2 to 36, the output digits that are greater than 9 are represented as lowercase letters: `a...z`.

For floating point numbers there are more options.

Firstly there's a basic function:

```
std::to_chars_result to_chars(char* first, char* last, FLOAT_TYPE value);
```

`FLOAT_TYPE` expands to `float`, `double` or `long double`.

The conversion works the same as with `printf` and in default ("C") locale. It uses `%f` or `%e` format specifier favouring the representation that is the shortest.

The next function adds `std::chars_format fmt` that let's you specify the output format:

```
std::to_chars_result to_chars(char* first, char* last,
                              FLOAT_TYPE value,
                              std::chars_format fmt);
```

Then there's the "full" version that allows also to specify `precision`:

```
std::to_chars_result to_chars(char* first, char* last,
                              FLOAT_TYPE value,
                              std::chars_format fmt,
                              int precision);
```

When the conversion is successful, the range `[first, last)` is filled with the converted string.

The returned value for all functions (for integer and floating point support) is `to_chars_result`, it's defined as follows:

```
struct to_chars_result {
    char* ptr;
    std::errc ec;
};
```

The type holds information about the conversion process:

- On **Success** - `ec` equals value-initialized `std::errc` and `ptr` is the one-past-the-end pointer of the characters written. Note that the string is not NULL-terminated.

- On **Error** - `ptr` equals `first` and `ec` equals `std::errc::invalid_argument`. `value` is unmodified.
- On **Out of range** - `ec` equals `std::errc::value_too_large` the range `[first, last)` in unspecified state.

An Example

To sum up, here's a basic demo of `to_chars`.

At the time of writing there was no support for floating point overloads, so the example uses only integers.

```
// Chapter String Conversions/to_chars_basic.cpp

#include <iostream>
#include <charconv> // from_chars, to_chars
#include <string>

int main()
{
    std::string str { "xxxxxxxx" };
    const int value = 1986;

    const auto res = std::to_chars(str.data(),
                                   str.data() + str.size(),
                                   value);

    if (res.ec == std::errc())
    {
        std::cout << str << ", filled: "
                  << res.ptr - str.data() << " characters\n";
    }
    else
    {
        std::cout << "value too large!\n";
    }
}
```

Below you can find a sample output for a set of numbers:

value	output
1986	1986xxxx, filled: 4 characters
-1986	-1986xxx, filled: 5 characters
19861986	19861986, filled: 8 characters
-19861986	value too large! (the buffer is only 8 characters)

The Benchmark

So far the chapter has mentioned huge performance potential of the new routines. It would be best to see some real numbers then!

This section introduces a benchmark that measures performance of `from_chars` and `to_chars` against other conversion methods.

How does the benchmark work:

- Generates vector of random integers of the size `VECSIZE`.
- Each pair of conversion methods will transform the input vector of integers into a vector of strings and then back to another vector of integers. This round-trip will be verified so that the output vector is the same as the input vector.
- The conversion is performed `ITER` times.
- Errors from the conversion functions are not checked.
- The code tests:
  - `from_char/to_chars`
  - `to_string/stoi`
  - `sprintf/atoi`
  - `ostringstream/istringstream`

You can find the full benchmark code in:

"Chapter String Conversions/conversion_benchmark.cpp"

Here's the code for `from_chars/to_chars`:

```
const auto numIntVec = GenRandVecOfNumbers(vecSize);
std::vector<std::string> numStrVec(numIntVec.size());
std::vector<int> numBackIntVec(numIntVec.size());

std::string strTmp(15, ' ');

RunAndMeasure("to_chars", [&]() {
    for (size_t iter = 0; iter < ITERS; ++iter)
    {
        for (size_t i = 0; i < numIntVec.size(); ++i)
        {
            const auto res = std::to_chars(strTmp.data(),
                                           strTmp.data() + strTmp.size(),
                                           numIntVec[i]);
            numStrVec[i] = std::string_view(strTmp.data(),
                                            res.ptr - strTmp.data());
        }
    }
    return numStrVec.size();
});

RunAndMeasure("from_chars", [&]() {
    for (size_t iter = 0; iter < ITERS; ++iter)
```

```
    {
        for (size_t i = 0; i < numStrVec.size(); ++i)
        {
            std::from_chars(numStrVec[i].data(),
                            numStrVec[i].data() + numStrVec[i].size(),
                            numBackIntVec[i]);
        }
    }
    return numBackIntVec.size();
});

CheckVectors(numIntVec, numBackIntVec);
```

`CheckVectors` - checks if the two input vectors of integers contains the same values, and prints mismatches on error.

The benchmark converts `vector<int>` into `vector<string>` and we measure the whole conversion process which also includes the string object creation.

Here are the results of running 1000 iterations on a vector with 1000 elements:

Method	GCC 8.2	Clang 7.0 Win	VS 2017 15.8 x64
`to_chars`	21.94	18.15	24.81
`from_chars`	15.96	12.74	13.43
`to_string`	61.84	16.62	20.91
`stoi`	70.81	45.75	42.40
`sprintf`	56.85	124.72	131.03
`atoi`	35.90	34.81	32.50
`ostringstream`	264.29	681.29	575.95
`stringstream`	306.17	789.04	664.90

Time is in milliseconds.

The machine: Windows 10 x64, i7 8700 3.2 GHz base frequency, 6 cores/12 threads (although the benchmark uses only one thread for processing).

- GCC 8.2 - compiled with `-std=c++17 -O2 -Wall -pedantic`, MinGW Distro[2]
- Clang 7.0 - compiled with `-std=c++17 -O2 -Wall -pedantic`, Clang For Windows[3]
- Visual Studio 2017 15.8 - Release mode, x64

[2] https://nuwen.net/mingw.html
[3] http://releases.llvm.org/dow4

Some notes:

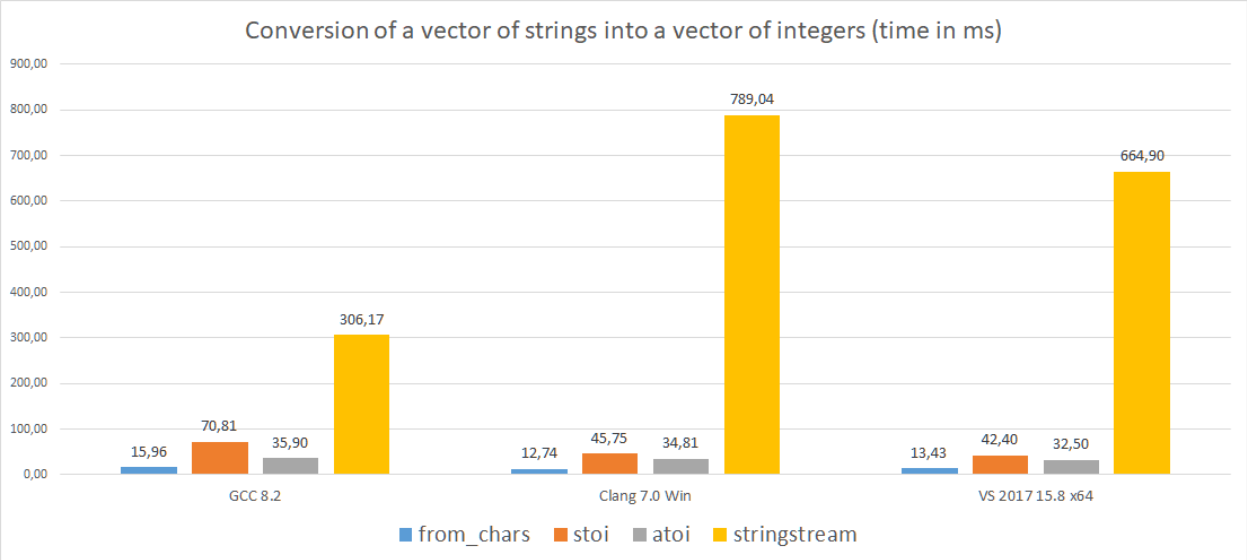
- On GCC `to_chars` is almost 3x faster than `to_string`, 2.6x faster than `sprintf` and 12x faster than `ostringstream`!
- On Clang `to_chars` is actually a bit slower than `to_string`, but ~7x faster than `sprintf` and surprisingly almost 40x faster than `ostringstream`!
- MSVC has also slower performance in comparison with `to_string`, but then `to_chars` is ~5x faster than `sprintf` and ~23x faster than `ostringstream`

Looking now at `from_chars` :

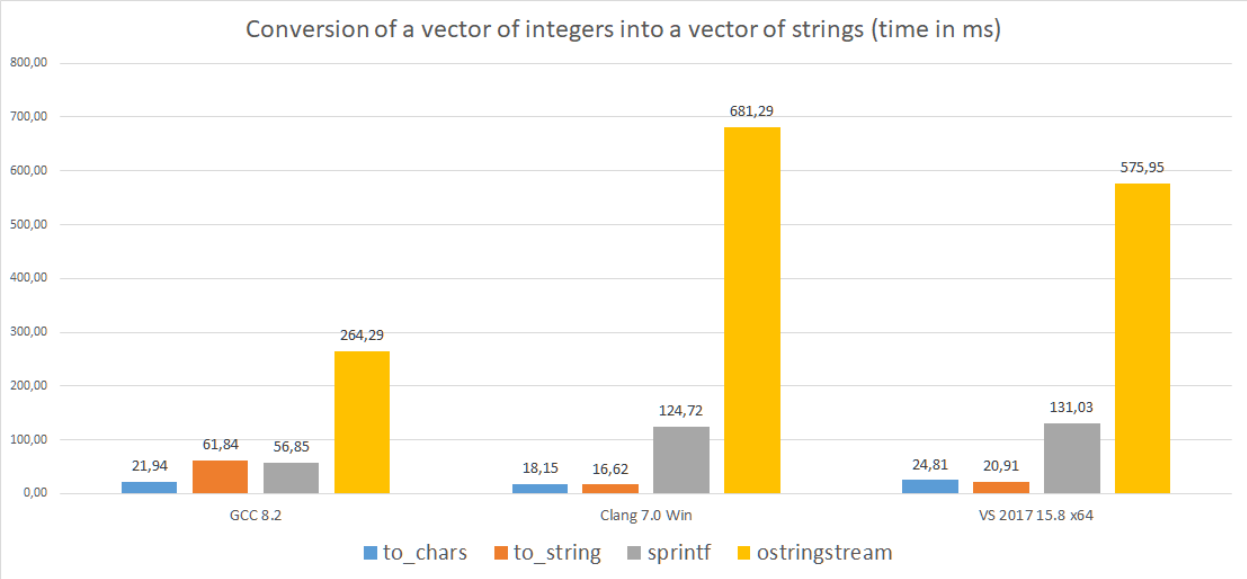
- On GCC it's ~4,5x faster than `stoi`, 2,2x faster than `atoi` and almost 20x faster than `istringstream`.
- On Clang it's ~3,5x faster than `stoi`, 2.7x faster than `atoi` and 60x faster than `istringstream`!
- MSVC performs ~3x faster than `stoi`, ~2,5x faster than `atoi` and almost 50x faster than `istringstream`!

As mentioned earlier, the benchmark also includes the cost of string object creation. That's why `to_string` (optimised for strings) might perform a bit better than `to_chars`. If you already have a char buffer, and you don't need to create a string object, then `to_chars` should be faster.

Here are the two charts built from the table above.



Strings into Numbers, time in milliseconds



Numbers into Strings, time in milliseconds

As always it's encouraged to run the benchmarks on your own before you make the final judgment. You might get different results in your environment, where maybe a different compiler or STL library implementation is available.

Summary

This chapter showed how to use two sets of functions `from_chars` - to convert strings into numbers, and `from_chars` that converts numbers into their textual representations.

The functions might look very raw and even C-style. This is a "price" you have to pay for having such low-level support, performance, safety and flexibility. The advantage is that you can provide a simple wrapper that exposes only the needed parts that you want.

Extra Info

The change was proposed in: P0067[4].

[4] https://wg21.link/P0067

Compiler support

Feature	GCC	Clang	MSVC
Elementary String Conversions	8.0[5]	7.0[6]	VS 2017 15.7/15.8[7]

[5] In progress, only integral types are supported
[6] In progress, only integral types are supported
[7] Integer support for `from_chars`/`to_chars` available in 15.7, floating point support for `from_chars` ready in 15.8. Floating point `to_chars` should be ready with 15.9. See STL Features and Fixes in VS 2017 15.8 | Visual C++ Team Blog.