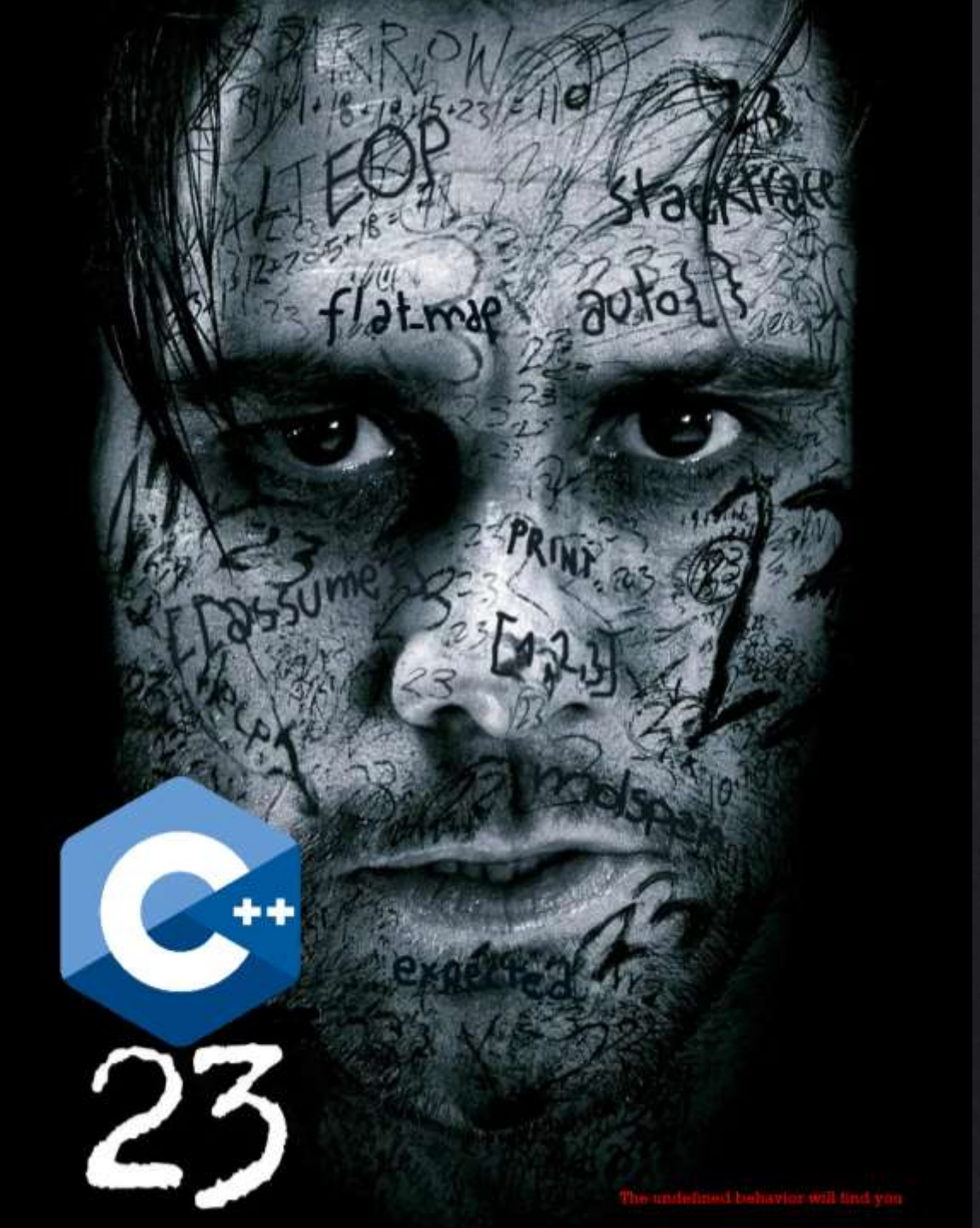

At the discovery of C++23

~~Jim Carrey~~

Marco Arena

C++23 is not a major release

- Informally called "the pandemic edition"
- Motivates adoption of C++20 by adding some missing pieces
- Introduces some additional bits (we are not going to see everything)
- By the way, 23 in Rome means “luck” (let’s say…)
- Table with current compiler support

In this talk

- **Language additions**
  - Explicit object parameter
  - `auto(x)`
  - Multidimensional subscript operator
  - Range-based for loop soap opera
  - `[[assume]]`
- **Library additions**
  - `import std` & `import std.compat`
  - `flat_{your associative container here}`
  - `expected`
  - `generator`
  - `mdspan`
  - `<stacktrace>`
  - `<print>`
  - Formatting ranges
  - Ranges additions
  - Other small bits

Language Additions

Explicit object parameter

- When writing generic code (e.g. libraries), supporting const and non-const member functions commonly leads to **code duplication**

```
struct Wrapper
{
    T& operator[](std::size_t idx)  { return m_data[idx]; }
    const T& operator[](std::size_t idx) const { return m_data[idx]; }
    // and what about T&& overloads?

    //...
};
```

Explicit object parameter

- You probably know a popular solution proposed by **Scott Meyers** in the old times

```
struct Foo {
    const T& foo() const {
        // do some work
        return bar;
    }

    T& foo() {
        return const_cast<T&>(const_cast<const Foo*>(this)->foo());
    }
};
```

Explicit object parameter

Explicit object parameter

- C++23 introduces a new way of specifying non-static member functions
- A great talk about this feature here

```
struct X {
    void foo(this X const& self); // same as void foo() const;
//  void foo() const; // Error: already declared
};
```

Explicit object parameter

You **are not allowed** to:

Add any trailing implicit parameter specifiers

```
void foo(this X const& self, int i) const; // Error!
void foo(this X const& self, int i) &&; // Error!
```

Refer implicity nor explicitly to `this`

```
struct X {
   int x;
   void foo(this X const& self, int i) {
     cout << x; // nope (implicitly)
     cout << this->x; // nope (explicitly)
     cout << self.x; // ok
   }
};
```

Override virtual functions

```
struct X {
   virtual void foo();
};

struct Bar : X {
   void foo(this const Bar&) override; // Error
    void foo(this const Bar&); // it's not overriding
    void foo(this const X&); // it's not overriding
};
```

Explicit object parameter

A pointer to member function with EOP is an ordinary function

```
struct Foo {
    int f(int, int) const&;
    int g(this Y const&, int, int);
};

auto pf = &Foo::f;
pf(y, 1, 2);              // error: pointers to member functions are not callable
(y.*pf)(1, 2);            // ok
std::invoke(pf, y, 1, 2); // ok

auto pg = &Foo::g;
pg(y, 3, 4);              // ok
(y.*pg)(3, 4);            // error: pg is not a pointer to member function
std::invoke(pg, y, 3, 4); // ok
```

Explicit object parameter

- For template member functions, this feature allows deduction of type and value category
- Based on C++ template deduction rules
- This is commonly called **deducing this**

```
struct X {
    template<typename Self>
    auto&& foo(this Self&& self, int i)  // auto&& foo(this auto&& self, int i)
    { }

X x;
x.foo(1);           // Self = X&       (decltype(self) = X& && = X&)
move(x).foo(1);     // Self = X        (decltype(self) = X&&)
const X xc;
xc.foo(1);          // Self = const X& (decltype(self) = const X& && = const X&)
```

Explicit object parameter

- **Use Case 1:** avoid code duplication

```
struct Wrapper
{
    T& operator[](std::size_t idx)  { return m_data[idx]; }
    const T& operator[](std::size_t idx) const { return m_data[idx]; }

    // covers both
    decltype(auto) operator[](this auto& self, size_t idx) { return m_data[idx]; }
};
```

Explicit object parameter

- **Use Case 2:** CRTP simplification

```
struct base {
    template <class Self>
    void f(this Self&& self);
};

struct derived : base {};

derived my_derived;
my_derived.f(); // in f, Self = derived& (this is not a dynamic dispatch!)
```

Explicit object parameter

- **Use Case 2:** CRTP simplification

```
// old school CRTP
template<typename Derived>
struct printer {
      auto& print(const char* message) const {
            std::cout << message << "\n";
            return static_cast<Derived&>(*this);
      }
};

struct better_printer : printer<better_printer> {
      auto& endl() const {
            std::cout << std::endl;
            return *this;
      }
};

better_printer printer;
printer.print("ciao").endl().print("hello");
//                 ^ we still get a better_printer here!
```

Explicit object parameter

```
// C++23 CRTP
struct printer {
    auto& print(this auto const& self, const char* message)  {
        std::cout << message << "\n";
        return self;
    }
};

struct better_printer : printer {
    auto& endl() const {
        std::cout << std::endl;
        return *this;
    }
};
```

Explicit object parameter

- **Use Case 3:** Recursive lambdas

```
auto fact = [](this auto&& self, int n) {
    if (n == 0)
        return 1;
    return n * self(n - 1);
};

cout << fact(5);
```

Explicit object parameter

- **Use Case 4:** Pass `this` by value (reasonable for small objects)

```
struct Foo
{
   int x;
   void bar(this auto self);
};

Foo foo {10};
foo.bar(); // the compiler can avoid allocating foo
```

Decay copy - auto(x)

- A motivating example:

```
vector<int> x = {1, 1, 2, 3, 4, 2, 2, 3};
erase(x, x.front()); // ?
```

https://wandbox.org/permlink/5Ajlb1GlIVE772hc

Decay copy - auto(x)

- A motivating example:

```
vector<int> x = {1, 1, 2, 3, 4, 2, 2, 3};
erase(x, x.front()); // ?

auto tmp = x.front(); // name + semantically wrong value category
erase(x, tmp);
```

https://wandbox.org/permlink/5Ajlb1GlIVE772hc

Decay copy - auto(x)

- A motivating example:

```
vector<int> x = {1, 1, 2, 3, 4, 2, 2, 3};
erase(x, x.front()); // ?

auto tmp = x.front(); // name + semantically wrong value category
erase(x, tmp);

erase(x, int{x.front()}); // not-generic (need to know ‘int’)
```

https://wandbox.org/permlink/5Ajlb1GlIVE772hc

Decay copy - auto(x)

- A motivating example:

```
vector<int> x = {1, 1, 2, 3, 4, 2, 2, 3};
erase(x, x.front()); // ?

auto tmp = x.front(); // name + semantically wrong value category
erase(x, tmp);

erase(x, auto{x.front()});
```

https://wandbox.org/permlink/5Ajlb1GlIVE772hc

Decay copy - auto(x)

- In other words, syntactic sugar for obtaining **a copy of a value** (actually, a **prvalue**)

```
void foo(const int& i)
{
   std::cout << &i;
}

int i = 10;
foo(auto{i});
```

Multidimensional subscript operator

- Subscript operator can now take an arbitrary number of subscripts (even 0)
- Cannot be non-member (as before)

```
struct Matrix
{
    decltype(auto) operator[](size_t x, size_t y) const
    {
        return m_data[x*m_cols + y];
    }
...

Matrix m = ...
std::cout << m[3, 1];
```

Multidimensional subscript operator

- 0-argument `[]` is possible:

```
struct Foo {
   auto operator[]() const;
};
struct Bar {
   auto operator[](auto...) const;
};

Foo foo; foo[]; // ok
Bar bar; bar[]; // ok
```

Multidimensional subscript operator

- By the way, **subscript** and **call operators** can be static in C++23:

```
struct Foo
{
    static auto operator[](auto...) const;
    static bool operator()(auto x);
};

auto is_even = [](int x) static { return x%2==0; };
```

Range-based for loop soap opera

```
{
    auto && __range = range-expression ;
    for (auto __begin = begin-expr, __end = end-expr; __begin != __end; ++__begin)
    {
        range-declaration = *__begin;
        loop-statement
    }
}
```
(until C++17)

```
{
    auto && __range = range-expression ;
    auto __begin = begin-expr ;
    auto __end = end-expr ;
    for ( ; __begin != __end; ++__begin)
    {
        range-declaration = *__begin;
        loop-statement
    }
}
```
(since C++17)
(until C++20)

```
{
    init-statement
    auto && __range = range-expression ;
    auto __begin = begin-expr ;
    auto __end = end-expr ;
    for ( ; __begin != __end; ++__begin)
    {
        range-declaration = *__begin;
        loop-statement
    }
}
```
(since C++20)

Range-based for loop soap opera

N. Josuttis et. al.: R2644R1: Final Fix of Broken Range-based `for` Loop

Project:	ISO JTC1/SC22/WG21: Programming Language C++
Doc No:	WG21 **P2644R1**
Date:	2022-11-11
Reply to:	Nicolai Josuttis (nico@josuttis.de)
Co-authors:	Herb Sutter, Titus Winter, Ha Bryce Adelstein Lelbach, Pe
Audience:	EWG, CWG
Issues:	cwg900, cwg1498, ewg120
Previous:	http://wg21.link/P2012

Final Fix of Broken
Rev 1

Range-based for loop soap opera

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Final Fix of Broken Range-based `for` Loop, Rev 1

Range-based for loop soap opera

- TL;DR: Lifetimes of all temporaries within **range-expression** are extended

```
// until C++23 undefined behavior if foo() returns by value
for (auto& x : foo().items()) { // extended until the end of the loop
    std::cout << x;
} // destroyed here
```

Range-based for loop soap opera

- TL;DR: Lifetimes of all temporaries within **range-expression** are extended

```
// until C++23 undefined behavior if foo() returns by value
for (auto& x : foo().items()) { // extended until the end of the loop
   std::cout << x;
} // destroyed here
```

- BTW, since C++23 we can also introduce alias declarations as init-statements:

```
for (using elem_t = decltype(v)::value_type; elem_t i : v)
```

[[assume]]

- Introduced support for **assumptions**
- Specifies that an expression will always evaluates to true at a given point
- The expression is not evaluated (aka: it's not a **contract**)
- If an assumption does not hold, the behavior is undefined (allowing optimizations)

```
[[assume(x > 0)]]; // the compiler may assume x is positive
g(x / 2); // more efficient code possibly generated
x = 3; auto z = x;
[[assume((h(), x == z))]]; // the compiler may assume x==z after h()
h();
g(x); // compiler may replace this with g(3)!
```

std::unreachable

- A standard way to invoke **undefined behavior**
- Compilers may use such information to optimize things away (e.g. impossible branches)
- It's, basically, `[[assume(false)]];`

```
string to_string(MyEnum e)
{
    switch (e) {
    case MyEnum::One: return "One";
    case MyEnum::Two: return "Two";
    ...
    default:
        unreachable();
    }
}
```

Library Additions

import std & import std.compat

- It's faster to bring in the entire standard library with `import std` (or `std.compat`) than it's to include a single header file (e.g. `<vector>`)
- Named macros (e.g. `assert`) are not available since modules don't expose macros
- Importing `std` brings in declarations and names in `std`, and also contents of C wrapper headers such as `<cstdio>` which provide functions like `std::printf`
- Importing `std.compat` brings in everything in std and adds the C runtime global namespaces such as `::printf`, `::fopen`. In other words, this makes easier to work with codebases that refer to many C runtime functions/types in the global namespace

```
import std;


int main() {
    std::cout << std::string{"hello"};
}
```

`flat_map` & friends

- Drop-in replacements for ordered non-flat types (`map`, `set`, `multi_map`, `multi_set`)
- **Different space** and **time complexity guarantees** than non-flat (aka: suitable for different use cases)
- Container adapters on **2 sequence** containers supporting **random access iterators** (keys, values)
- Still **ordered**
- Underneath, **contiguity is not required** (the API is a bit more flexible)
- Compared to non-flat types:
  - ☹ **Insertions** and **removals** are more expensive (linear + possibly reallocation) and invalidate iterators
  - ☹ **Exception safety** is weaker because of data movement
  - ☹ Can't store **scoped types** (non-copyable & non-movable)
  - ☺ Faster iteration & cache-friendliness, random access, smaller memory usage (modulo backend)
  - ☺ Faster allocation and deallocation (modulo backend)

flat_map & friends

```
flat_map<int, std::string> flat { {1, "one"}, {2, "two"}, {3, "three"} };
cout << flat.lower_bound(1)->second << "\n";

for (auto [k, v] : flat) {
    std::cout << k << ": " << v << '\n';
}

// real use case
flat_map<std::string, std::vector<double>> parameters;
auto keys = SomeApi_GetKeys();
auto vals = SomeApi_GetVals();
parameters.replace(move(keys), move(vals));
// a bunch of queries on parameters (not changing anymore)
```

expected

- **Vocabulary type** to store either an expected value of type `T` or an error of type `E`
- Never valueless (e.g. `expected<T,E>{}` contains a `T{}`)
- No dynamic memory involved
- Supports some monadic operations (C++23 adds monadic operations to `std::optional` too)
- You know Rust's `Result`?

```
expected<double, error_code> parse(string_view sv) {
    // ... if parse error ...
    return unexpected(make_error_code(errc::invalid_argument));
}

auto result = parse(user_input);
if (result.has_value()) {
    // process result...
}
```

expected

- More interesting when used "functionally":

```
expected<coupon_info, coupon_error> find_coupon(string_view url);
expected<coupon_info, coupon_error> check_active(const coupon_info& ci);
expected<coupon_info, coupon_error> check_expired(const coupon_info& ci);

auto out = find_coupon("MAKEIT20")
    .and_then(check_active)
    .and_then([&](const auto& ci) {
        return check_expired(ci, sys_days{ January / 1 / 2027 });
    }).transform([](const auto& ci) {
        return ci.amount;
    });
```

generator

- A view of the elements yielded by the evaluation of a coroutine (models `view` and `input_range` concepts)
- We have support for nested generators through `elements_of`
- Check out Alberto Barbati's awesome 30-min talk, a reference implementation is here

```
generator<string> files() {
    for (auto entry : filesystem::directory_iterator{"."}) {
        co_yield entry.path().string();
    }
}

for (auto s : files() | views::take(3)) {
        std::cout << s << "\n";
}
```

mdspan

- **Multi-dimensional span** (non-owning view into a contiguous sequence of data)
- Provides minimal access operations (not slicing that should be merged into C++26)
- Supports:
  - dynamic and static **extents** (can be mixed together)
  - **layout** policies (e.g. Fortran-style's `layout_left`)
  - **accessor** policies to map indices to values

```
template<
    class T,                                  // data type
    class Extents,                            // shape (dimension)
    class LayoutPolicy = layout_right,        // [i,j...] -> offset
    class AccessorPolicy = default_accessor<T>  // offset -> T& (ownership)
> class mdspan;
```

mdspan

- `std::extents` allows to embed the **shape** (possibly mixing compile-time and run-time sizes)

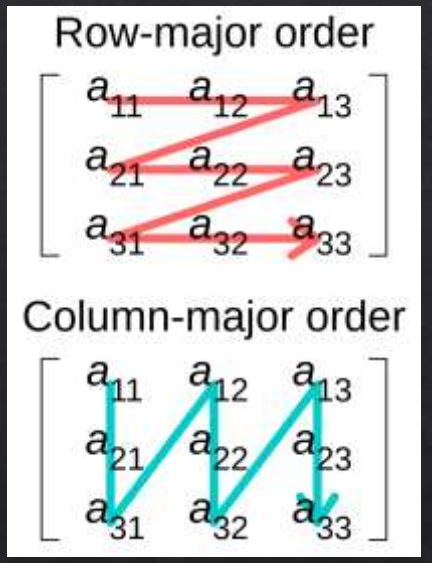
```
int buffer[6] = ...;
auto s1 = mdspan(buffer, 3, 2); // all run-time extents

extents<int, 2, 3> shape;
auto s2 = mdspan(buffer, shape); // all compile-time extents
static_assert(s.extent(0)==2, "Rows are two");
static_assert(s.extent(1)==3, "Cols are three");

// mixing compile-time and run-time extents
using shape_t = extents<int, dynamic_extent, 3, 320, 380>;
auto tensor = mdspan<float, shape_t>(imageReshaped, 25);
```

mdspan

- `LayoutPolicy` defines how to **map** a multi-dimensional **index** into a one-dimensional **offset** (by default, `layout_right` that is C-style row-major layout)
- In addition to `layout_right` and `layout_left` (column-major), the standard provides `layout_stride` for regularly strided dimensions



- `AccessorPolicy` specifies how to **obtain a reference from an offset**
- Handles memory access patterns such as remote and atomic access, compression, non-aliasing semantics

Play with mdspan here (production-quality implementation + some doc here)

<stacktrace>

- Minimal and handy abstraction on **invocation sequences** (e.g. main→foo→bar)
- Functions and constructors are **lazy** (information brought to you on demand)
- Frames are stored in **dynamic memory** (support for custom allocators)
- Represents a **snapshot** of the **stacktrace** as a `SequenceContainer & ReversibleContainer`
- Do not expect Boost.Stacktrace's completeness

```
auto trace = stacktrace::current(); // all the entries
cout << trace << "\n"; // default pretty printing
cout << trace.size(); << "\n"; // number of entries (depth of the stack)
cout << trace[1].source_file()
```

<stacktrace>

```
int main() {
    set_terminate([]() {
        if (current_exception())
        {
            cout << "Something bad happened...\n\n";
            cout << stacktrace::current() << "\n";
        }
        abort();
    });
    ...
}
```

<stacktrace>

```
void api_facade()
{
   for (const auto& s : views::reverse(stacktrace::current()))
   {
      log(s.to_string());
   }
}
```

<print>

- **Formats** (`std::format`) a string and prints the result to a (`FILE*`) stream
- If the stream is omitted, the standard C output stream (`stdout`) is used
- Better than `std::cout` because – for example – the latter ignores encoding

```
#include <print>

print("hello {}\n", 10);
println("hello {}", 10);

if (FILE* stream = fopen(c:/temp/tmp.txt, "w"))
{
    print(stream, "File: {}", some_content);
    fclose(stream);
}
```

https://wandbox.org/permlink/H5MgM63fu4tV5RDc

Ranges additions

- A bunch of new views:
  - `repeat`
  - `cartesian_product`
  - `enumerate`
  - `zip, zip_transform`
  - `join_with`
  - `slide, stride, chunk, chunk_by, adjacent, adjacent_transform, pairwise, pairwise_transform`
  - `as_const, as_rvalue`
- A bunch of new algorithms:
  - `find_last, find_last_if, find_last_not_if`
  - `contains, contains_subrange`
  - `starts_with, ends_with`
  - `shift_left, shift_right`
  - `iota`
  - `fold_left, fold_right, fold_left_first, fold_right_last, fold_left_with_iter, fold_left_first_with_iter`
- Also, `ranges::to` which constructs a non-view (aka: container) from a range

Formatting ranges

- `std::format` supports ranges (can't change separators, in case you are wondering)

```
vector v = {1,2,3};
cout << format("{}", v); // [1, 2, 3]

queue<int> q; v.push(1); v.push(2);
print("{}", q); // [1, 2]

map<string, vector<int>> cache = {{"1", {1,2,3}},{"5", {10,20}}};
print("{}", cache); // {"1": [1, 2, 3], "5": [10, 20]}
```

https://wandbox.org/permlink/UFEfI3FBTkHLwbiW

Other Library Additions

Fixed width floating-point types

- New types added:

```
std::float16_t
std::float32_t
std::float64_t
std::float128_t
std::bfloat16_t
```

string::resize_and_overwrite

- Avoids zero-initializing a `std::string` when intended to be used as a char array to be filled (e.g. by a C API)

```
std::string str(1024, '\0'); // might be expensive
str.resize(External_Api(s1.data(), s1.size()));

// using this feature:
std::string str; // no initialization
str.resize_and_overwrite(1024, [](char* raw, size_t n){
  return External_Api(raw, n);
});
```

string::resize_and_overwrite

```
std::string str; // no initialization
str.resize_and_overwrite(1024, [](char* raw, size_t n){
  return External_Api(raw, n);
});
```

string::resize_and_overwrite

```
std::string str; // no initialization
str.resize_and_overwrite(1024, [](char* raw, size_t n){
  return External_Api(raw, n);
});
```

string::resize_and_overwrite

```
std::string str; // no initialization
str.resize_and_overwrite(1024, [](char* raw, size_t n){
  return External_Api(raw, n);
});
```

string::resize_and_overwrite

```
std::string str; // no initialization
str.resize_and_overwrite(1024, [](char* raw, size_t n){
  return External_Api(raw, n);
});
```

spanstream

- Added support for fixed character buffer I/O operations

```
char* data_from_external_api = api_get_data(); // "10 20"
ispanstream stream{ span{data_from_external_api} };
int i, j;
stream >> i >> j;
cout << i << " " << j; // 10 20

char* destination[10]{};
ospanstream oss{ span{out} };
oss << "too many characters..." << "\n"; // won't allocate more memory
```

move_only_function

- Like `std::function` but it's not copyable and **supports move-only types**

```
move_only_function<int()> fun = [p = make_unique<int>(1)] {
    return *p;
});
```

- Note that this code is now ill-formed *:

```
function<const int&()> F([] { return 42; }); // Error since C++23
move_only_function<const int&()> F([] { return 42; }); // ditto
int x = F(); // until C++23 this was UB
```

*) C++23 introduces traits to detect reference binding to temporary
`reference_constructs_from_temporary` and `reference_converts_from_temporary`

to_underlying

- Converts an enumeration to its underlying type (e.g. `int`)
- Shortcut for `static_cast<underlying_type_t<Enum>>(e)`

```
enum class Pippo {A=20, B, C};
cout << to_underlying(Pippo::A); // 20
```

Associative containers heterogeneous erasure

- You remember heterogenous lookup for associative containers (added to ordered containers in C++14 and to unordered in C++20)?
- Well, the capability has been extended to **erasure** as well

```
map<std::string, int, less<>> m = {...};
const char* key = "some_key";
m.erase(key); // no implicit conversion to string
```

Takeaway

- C++23 is not a major release and **mostly** introduces new **library features**
- **Explicit Object Parameter** is probably the most important language addition
- We are now **aware of things** that can spring up like mushrooms in codebases
- To stay relevant, **learn** how these things **work** and their **impact**
- As usual: **adding enables removing**
- Code and slides on github

Questions?