Implementing **“static”** **control flow** in C++14

http://vittorioromeo.info
vittorio.romeo@outlook.com

cppcon the c++ conference

Bloomberg
vromeo5@bloomberg.net

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http://github.com/SuperV1234/cppcon2016

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Talk overview

- What is **“static”** control flow?
- Compile-time branching.
  - History of `static if` in C++.
  - C++17: `if constexpr`.
  - C++14: `static_if`.
- `static_if` implementation details.
- Compile-time iteration.
  - `for_each_argument`.
  - `static_for`.

Talk overview

- What is **“static”** control flow?
- Compile-time branching.
  - History of `static if` in C++.
  - C++17: `if constexpr`.
  - C++14: `static_if`.

slides

- `static_if` implementation details.
- Compile-time iteration.
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- What is **“static”** control flow?
- Compile-time branching.
  - History of `static if` in C++.
  - C++17: `if constexpr`.
  - C++14: `static_if`.

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- `static_if` implementation details.
- Compile-time iteration.
  - `for_each_argument`.
  - `static_for`.

code + comments

What is **“static”** control flow?

- `static` is a specifier with multiple meanings in C++.
- It’s also a word commonly used by developers to refer to **compile-time control flow**.
- Existing languages, such as D, have powerful compile-time constructs like `static if`.
- Goals of this talk:
  - Understand the benefits of static control flow.
  - Look at the history of `static_if` proposals in C++, analyze `if constexpr`.
  - Implement two C++14 constructs: `static_if` and `static_for`.

Example: `static if` in D

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```
template INT(int i)
{
    static if (i == 32)
        alias INT = int;
    else static if (i == 16)
        alias INT = short;
    else
        static assert(0);
}
```

Example: `static if` in D

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template INT(int i)
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    static if (i == 32)
        alias INT = int;
    else static if (i == 16)
        alias INT = short;
    else
        static assert(0);
}
```

```
template<int i>
struct INT;

template<>
struct INT<32>
{
    using type = int;
};

template<>
struct INT<16>
{
    using type = short;
};
```

Example: handling variadic argument packs *(traditional)*

```
template <class T>
void f(T&& t)
{
    // handle one T
}
```

```
template <class T, class... Rest>
void f(T&& t, Rest&&... r)
{
    f(t);
    // handle the tail
    f(r...);
}
```

Example: handling variadic argument packs *(static if)*

```
template <class T, class... Rest>
void f(T&& t, Rest&&... r)
{
    f(t);

    if constexpr(sizeof...(r))
    {
        // handle the tail
        f(r...);
    }
}
```

Example: { } vs ( ) object construction *(traditional)*

```
template <class T, class... Args>
enable_if_t<is_constructible_v<T, Args...>, unique_ptr<T>>
make_unique(Args&&... args)
{
    return unique_ptr<T>(new T(forward<Args>(args)...));
}

template <class T, class... Args>
enable_if_t<!is_constructible_v<T, Args...>, unique_ptr<T>>
make_unique(Args&&... args)
{
    return unique_ptr<T>(new T{forward<Args>(args)...});
}
```

Example: { } vs ( ) object construction *(static if)*

```
template <class T, class... Args>
auto make_unique(Args&&... args)
{
    if constexpr(is_constructible_v<T, Args...>)
    {
        return unique_ptr<T>(new T(forward<Args>(args)...));
    }
    else
    {
        return unique_ptr<T>(new T{forward<Args>(args)...});
    }
}
```

History of `static if` proposals - 1

- The previous examples were taken from proposal P0128R0:
  - "constexpr if" - *Ville Voutilainen*
- This paper was originally created as a "resurrection" of the very controversial previous "static if" N3322 and N3329 proposals:
  - "A Preliminary Proposal for a Static if" - *Walter E. Brown*
  - "static if declaration" - *W. Bright, H. Sutter, A. Alexandrescu*
- The two above proposals were considered harmful in N3613, due to their unintuitive scope rules and inconsistency with the rest of the language:
  - "Static if considered" - *B. Stroustrup, G. Dos Reis, A. Sutton*

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2015

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History of `static if` proposals - 2

- Starting with N4461 by *V. Voutilainen*, the idea of a compile-time `if` construct with familiar scope rules began to gain traction.
  - "Static if resurrected" – *Ville Voutilainen*
- Eventually, the proposed syntax and standard wording was revised multiple times in P0128R0, P0128R1, P0292R0, and P0292R1.
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2016

History of `static if` proposals - 3

- The final revision, P0292R2, was accepted for C++17:
  - "constexpr if: A slightly different syntax"
    - Jens Maurer

if constexpr(…) – *valid C++17 example* - 1

```
template <class T, class... Rest>
void f(T&& t, Rest&&... r)
{
    f(t);

    if constexpr(sizeof...(r))
    {
        // handle the tail
        f(r...);
    }
}
```

if constexpr(…) – *valid C++17 example* - 2

```
template <class T, class... Args>
auto make_unique(Args&&... args)
{
    if constexpr(is_constructible_v<T, Args...>)
    {
        return unique_ptr<T>(new T(forward<Args>(args)...));
    }
    else
    {
        return unique_ptr<T>(new T{forward<Args>(args)...});
    }
}
```

`if constexpr(…)` – rules

- Restricted to block scopes.
- Always going to establish a new scope.
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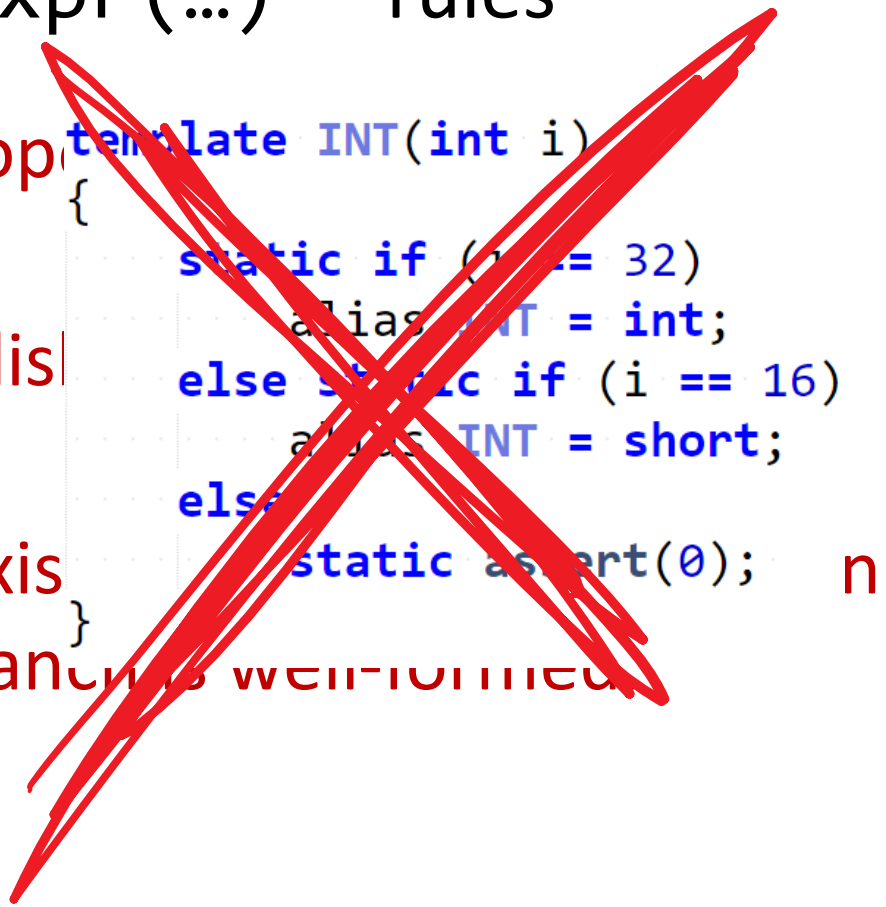

`if constexpr(…)` – rules

- Restricted to block scopes.
- Always going to establish a new scope.
- Required that there exists values of the condition so either condition branch is well-formed.

`if constexpr(…)` – branch chaining

```
if constexpr (cond0)
    statement0;
else if constexpr (cond1)
    statement1;
else if constexpr (cond2)
    statement2;
else
    statement3;
```

“Do I have to wait until C++17 is supported by my company/architecture?”

C++14 `static_if` – *example (1)*

- Example situation:
  - Multiple food-related classes with slightly different interfaces.
- Goal:
  - Create a generic `consume(x)` function that will accept any kind of food instance and will print something to `stdout`.

```
struct banana
{
    void eat() { }
};

struct peanuts
{
    void eat() { }
};

struct water
{
    void drink() { }
};

struct juice
{
    void drink() { }
};
```

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struct juice
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};
```

C++14 `static_if` – *example (2)*

- Both if `constexpr` and my `static_if` implementation require a *constant expression* as their branching condition.
- Let's define some `constexpr bool` variable templates to categorize the foods depending on their interface.

```
template <typename T>
constexpr bool is_solid{false};

template <>
constexpr bool is_solid<banana>{true};

template <>
constexpr bool is_solid<peanuts>{true};
```

```
template <typename T>
constexpr bool is_liquid{false};

template <>
constexpr bool is_liquid<water>{true};

template <>
constexpr bool is_liquid<juice>{true};
```

```cpp
template <typename T>
auto consume(T&& x)
{
    static_if(bool_v<is_solid<T>>)
        .then([](auto&& y)
            {
                y.eat();
                std::cout << "eating solid\n";
            })
        .else_if(bool_v<is_liquid<T>>)
        .then([](auto&& y)
            {
                y.drink();
                std::cout << "drinking liquid\n";
            })
        .else_([](auto&&)
            {
                std::cout << "cannot consume\n";
            })(FWD(x));
}
```

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template <typename T>
auto consume(T&& x)
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The implementation requires the condition to be wrapped inside a compile-time boolean variable wrapper: that's what `bool_v` is for.

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```cpp
template <typename T>
auto consume(T&& x)
{
    static_if(bool_v<is_solid<T>>)
        .then([](auto&& y)
        {
```

```cpp
template <bool TX>
using bool_ = std::integral_constant<bool, TX>;

template <bool TX>
constexpr bool_<TX> bool_v{};
```

```cpp
        .else_([](auto&&)
        {
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                    std::cout << "drinking liquid\n";
                })
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                })(FWD(x));
}
```

Wrapping types inside values *(and vice versa)* is what allows amazing libraries such as `boost::hana` *(by Louis Dionne)* or `fit` and `tick` *(by Paul Fultz II)* to provide extremely powerful, clean, and intuitive metaprogramming facilities.

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auto consume(T&& x)
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```
                y.drink();
```

More info regarding "type-value encoding"/"dependent typing":
http://pfultz2.com/blog/2015/01/24/dependent-typing/
http://boostorg.github.io/hana/index.html#tutorial-type

```
            })(FWD(x));
}
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```
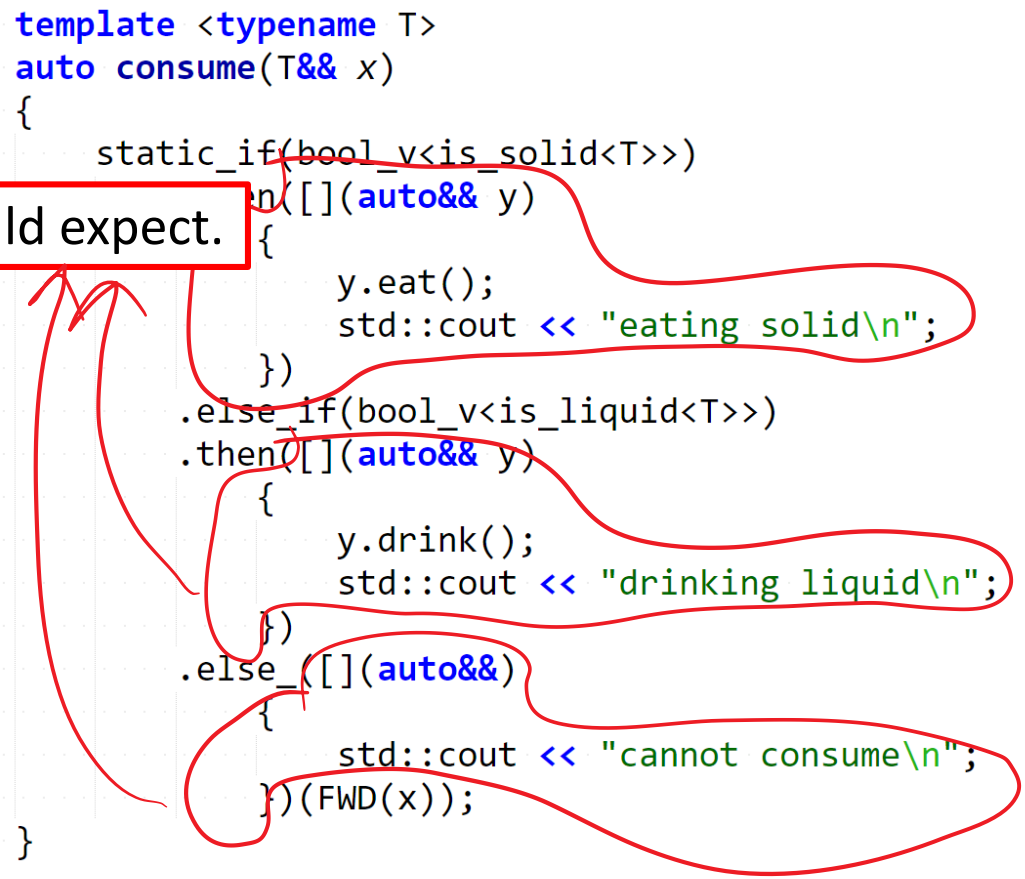

Scope rules are what you would expect.



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        .else_([](auto&&)
            {
                std::cout << "cannot consume\n";
            })(FWD(x));
}
```

Think of every branch of the `static_if` as a template function that **will only be instantiated if the predicate matches**.

In this example, even if `y.eat()` does not exist, **we won't get a compilation error**, because the branch won't be instantiated.

```
template <typename T>
auto consume(T&& x)
{
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        .then([](auto&& y)
            {
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                std::cout << "eating solid\n";
            })
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            {
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[](auto&& y)
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```
[](auto&& y)
{
    y.eat();
    std::cout << "eating solid\n";
}
```

```
struct lambda
{
    template <typename T>
    auto operator()(T&& y) const
    {
        y.eat();
        std::cout << "eating solid\n";
    }
};
```

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[](auto&& y)
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    auto operator()(T&& y) const
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C++14 `static_if` – instantiating matching branch

- What allows `static_if` branches to only be instantiated when the condition is `true`?
- *"Passing the argument back to `static_if`"* with the final call does that: thanks to this trick, the instantiation of the branches is *"delayed"* so that potentially invalid branches do not cause a compilation error unless chosen.

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}
```

Let’s analyze the technique, step-by-step.

Step 0: call `consume`

```
consume(juice{});
```

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auto consume(T&& x)
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Imagine that the entire `static_if` *"collapses"* to the first matching branch's body. The body can then be called with the argument `FWD(x)`.

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Imagine that the entire `static_if` *"collapses"* to the first matching branch's body. The body can then be called with the argument `FWD(x)`.

C++14 `static_if` – capture?

- Would capturing the variable work?

```
consume(juice{});
```

```
static_if(bool_v<is_solid<T>>)
    .then([&x]
        {
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            std::cout << "eating solid\n";
        })
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    .else_([]
        {
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```

Nope.

C++14 `static_if` – capture?

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  the varia
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consume(jui
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```
struct juice
{
    void drink() { }
};

struct lambda
{
    juice& x;

    auto operator()() const
    {
        x.eat();
        std::cout << "ate solid food\n";
    }
};
```

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```
solid\n";
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```
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```

This gets “immediately instantiated” and causes a compilation error.

code();

Questions?

http://vittorioromeo.info
http://github.com/SuperV1234

vittorio.romeo@outlook.com
vromeo5@bloomberg.net

Thank you for attending!