

Checking *expression validity* in C++11/14/17

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```
struct Cat
{
    void meow() const { cout << "meow\n"; }
};

struct Dog
{
    void bark() const { cout << "bark\n"; }
};
```

```
template <typename T>
void make_noise(const T& x)
{
    // Pseudocode:

    if( <`x.meow()` is well-formed> )
    {
        x.meow();
    }
    else if( <`x.bark()` is well-formed> )
    {
        x.bark();
    }
    else
    {
        <compile-time error>
    }
}
```

```
make_noise(Cat{}); // "meow"  
make_noise(Dog{}); // "bark"  
make_noise(int{}); // compile-time error
```

```
template <typename T>
void make_noise(const T& x){ /* ? */ }
```

- C++11: `std::void_t` and `std::enable_if`.
- C++14: `boost::hana::is_valid` and `vrn::core::static_if`.
- C++17: `if constexpr(...)`, `constexpr` lambdas, and `std::is_callable`.

C++11

`std::void_t` and `std::enable_if`

Combining `std::void_t` with `std::enable_if` allows us to detect *ill-formed* expressions in SFINAE contexts.

- "Modern Template Metaprogramming: A Compendium"
by *Walter E. Brown* at CppCon 2014

```
template <typename ... >  
using void_t = void;
```

(`void_t` was standardized in C++17, but can be implemented in C++11.)


```
template <typename, typename = void>
struct has_meow : std::false_type { };

template <typename T>
struct has_meow
<
    T,
    void_t<decltype(std::declval<T>().meow())>
>
: std::true_type { };
```

Instantiating `has_meow<T>` will attempt to evaluate

```
void_t<decltype(std::declval<T>().meow())>
```

If `declval<T>().meow()` is *well-formed*,

```
void_t<decltype(std::declval<T>().meow())>
```

will evaluate to `void`, and `has_meow`'s `std::true_type` specialization will be taken.

```
template <typename, typename = void>
struct has_meow : std::false_type { };

template <typename T>
struct has_meow<T, void_t<decltype(std::declval<T>().meow())>> // <<<
    : std::true_type { }; // <<<
                        // <<<
```

If `declval<T>().meow()` is *ill-formed*,

```
void_t<decltype(std::declval<T>().meow())>
```

will be *ill-formed* as well, *SFINAE-ing* away the `std::true_type` specialization. All that's left is the `std::false_type` specialization.

```
template <typename, typename = void> // <<<
struct has_meow : std::false_type { }; // <<<

template <typename T>
struct has_meow<T, void_t<decltype(std::declval<T>().meow())>>
    : std::true_type { };
```

| How does `void_t` work?

```
auto meows = has_meow<Cat>{};
```

...is equivalent to...

```
auto meows = has_meow<Cat, void>{};
```

...because of the default `void` parameter.

The compiler takes into account *partial specializations*.

- `T` is matched to `T`
- `void` is matched to

```
void_t<decltype(std::declval<T>().meow())>
```

If `void_t<decltype(std::declval<T>().meow())>` doesn't get *SFINAE-d away*, both the types of the original templates and the specialization match.

The partial specialization is prioritized and chosen.

If the original template's second parameter wasn't defaulted to `void`, it would have been chosen over the partial specialization!

After defining the `has_bark` detector class (*which is trivial to implement, as well*), all that's left to do is use `std::enable_if` to constrain `make_noise`.

```
template <typename T>
auto make_noise(const T& x)
    → typename std::enable_if<has_meow<T>{}>::type
{
    x.meow();
}
```

```
template <typename T>
auto make_noise(const T& x)
    → typename std::enable_if<has_bark<T>{}>::type
{
    x.bark();
}
```

C++11 implementation issues:

- A *detector class* must be defined for **every** expression to check.
 - The class **cannot be defined locally**.
- `std::enable_if` must be used to constrain multiple versions of the same function.
 - It is not possible to "*branch*" **locally** at compile-time.
 - It is necessary to **repeat** the function signature.

C++14

`boost::hana::is_valid` and `vrn::core::static_if`

We can solve the aforementioned issues thanks to

♥ *generic lambdas* ♥

Generic lambdas are "*templates in disguise*" - they provide a *SFINAE-friendly* context.

```
auto l = [](auto x){ return x; };
```

...is somewhat equivalent to...

```
struct ANONYMOUS  
{  
    template <typename T>  
    auto operator()(T x) const { return x; }  
};
```

Let's take advantage of that...

```
auto has_meow =  
    is_valid([](auto&& x) → decltype(x.meow())){});  
  
static_assert(has_meow(Cat{}), "");  
static_assert(!has_bark(Cat{}), "");
```

- `has_meow` can be **locally** instantiated in any scope.
- Terser & nicer syntax.

| How can we implement `is_valid` ?

```
template <typename TF>
constexpr auto is_valid(TF)
{
    return validity_checker<TF>{};
}
```

```
template <typename TF>
struct validity_checker
{
    template <typename ... Ts>
    constexpr auto operator()(Ts&& ... ) const
    {
        return is_callable<TF(Ts ... )>{};
    }
};
```

Remember that `TF` is the type of:

```
[ ](auto&& x) → decltype(x.meow()) { }
```

How can we implement `is_callable` ?

```
template <typename, typename = void>
struct is_callable : std::false_type { };

template <typename TF, class ... Ts>
struct is_callable
<
    TF(Ts ... ),

    void_t<decltype(
        std::declval<TF>()(std::declval<Ts>() ... )
    )>
>
: std::true_type { };
```

`is_valid` solves the first C++11 *annoyance*.

- Detectors can be instantiated locally.

Solving the second issue (*local compile-time branching*) is slightly more complicated, but **it can be done**.

I explain how in my **CppCon 2016 talk**:

"Implementing `static` control flow in C++14".

```

template <typename T>
auto make_noise(const T& x)
{
    auto has_meow = is_valid([](auto&& x)
        → decltype(x.meow()){ });

    auto has_bark = is_valid([](auto&& x)
        → decltype(x.bark()){ });

    static_if(has_meow(x))
        .then([&x](auto){ x.meow(); })

        .else_if(has_bark(x))
        .then([&x](auto){ x.bark(); })

        .else_([](auto)
            {
                struct cannot_meow_or_bark;
                cannot_meow_or_bark{};
            })();
}

```


Is it *nicer* than the C++11 version? **Debatable.**

There are some *objective advantages*, though:

- Expression validity detector instantiation is **local to the function scope**.
- There is a **single overload** of `make_noise` .
- Compile-time branching is **local to the function scope**.

- `boost::hana::is_valid` is a production-ready C++14 implementation of the above `is_valid` function.
- You can find my `static_if` implementation in `vrn::core::static_if`.

C++14 implementation issues:

- `is_valid` has to be assigned to a variable in order to be used in a **constant expression**.
 - This happens because lambdas are not `constexpr`.
- **Verbosity.**
 - `static_if` makes the code much less readable.
 - Having to create a lambda with a `decltype(...)` *trailing return type*.

C++17

- `if constexpr(...)`
- `constexpr` lambdas
- `std::is_callable`
- Variadic macro *black magic*

```
template <typename T>
auto make_noise(const T& x)
{
    if constexpr(IS_VALID(_0.meow())(T))
    {
        x.meow();
    }
    else if constexpr(IS_VALID(_0.bark())(T))
    {
        x.bark();
    }
    else
    {
        struct cannot_meow_or_bark;
        cannot_meow_or_bark{};
    }
}
```

`IS_VALID(_0.meow())(T)` is a variadic macro that:

- Takes an expression built with *type placeholders*.
- Takes some *types*.
- Evaluates to `true` if the expression is valid for the given types.

// Can `T` be dereferenced?

```
IS_VALID(*_0)(T);
```

// Can `T0` and `T1` be added together?

```
IS_VALID(_0 + _1)(T0, T1);
```

// Can `T` be streamed into itself?

```
IS_VALID(_0 << _0)(T);
```

// Can a tuple be made out of `T0`, `T1` and `float`?

```
IS_VALID(std::make_tuple(_0, _1, _2))(T0, T1, float);
```


IS_VALID can be used in contexts where only a *constant expression* is accepted such as **static_assert(...)** or **if constexpr(...)**.

| What is this magic!?

Let's begin by defining some utilities...

```
template <typename T>
struct type_w
{
    using type = T;
};

template <typename T>
constexpr type_w<T> type_c{};
```

`type_c` is a *constexpr variable template* that wraps a type into a value.

```
constexpr auto wrapped_int = type_c<int>;  
  
using unwrapped_int =  
    typename decltype(wrapped_int)::type;
```

`type_c` is useful because it can be passed to *template functions* like a regular value, **retaining the type information**.

```
template <typename TF>  
constexpr auto is_valid(TF)  
{  
    return validity_checker<TF>{};  
}
```

Identical to the previous version.

```

template <typename TF>
struct validity_checker
{
    template <typename ... Ts>
    constexpr auto operator()(Ts ... ts)
    {
        return std::is_callable<
            TF(typename decltype(ts)::type ... )
        >{};
    }
};

```

Expects a bunch of `type_c` values, then unwraps them into `std::is_callable` (*standardized in C++17*).

The lambda passed as `TF` is almost identical as well:

```
is_valid([](auto _0) constexpr → decltype(_0.meow())){ }
```

...but there's a `constexpr` in there!

constexpr lambdas were standardized in C++17.

```
// Make sure that `int*` can be dereferenced.  
static_assert(  
    is_valid([](auto _0) constexpr → decltype(*_0){})  
    (type_c<int);
```

This technique is very verbose...

```
template <typename T>
auto make_noise(const T& x)
{
    if constexpr(is_valid([](auto _0) constexpr
        →decltype(_0.meow()))(T))
    {
        x.meow();
    }
    else if constexpr(is_valid([](auto _0) constexpr
        →decltype(_0.bark()))(T))
    {
        x.bark();
    }
    else
    {
        struct cannot_meow_or_bark;
        cannot_meow_or_bark{};
    }
}
```

That's why we need a **macro**.

```
#define IS_VALID_1_EXPANDER(type0) \  
    (type_c<type0>)  
  
#define IS_VALID_1( ... ) \  
    is_valid( \  
        [](auto _0) constexpr \  
            → decltype(__VA_ARGS__){} \  
    ) \  
    IS_VALID_1_EXPANDER
```

```
#define IS_VALID_2_EXPANDER(type0, type1) \
    (type_c<type0>, type_c<type1>)

#define IS_VALID_2( ... ) \
    is_valid( \
        [](auto _0, auto _1) constexpr \
            → decltype(__VA_ARGS__){} \
        ) \
    IS_VALID_2_EXPANDER
```

```
#define IS_VALID_3_EXPANDER(type0, type1, type2) \  
    (type_c<type0>, type_c<type1>, type_c<type2>)  
  
#define IS_VALID_3( ... ) \  
    is_valid( \  
        [](auto _0, auto _1, auto _2) constexpr \  
            → decltype(__VA_ARGS__){} \  
        ) \  
    IS_VALID_3_EXPANDER
```

...with some `vrn_pp` *preprocessor metaprogramming* and some pre-generated code...

```
#define IS_VALID( ... ) \
    VRM_PP_CAT( \
        IS_VALID_, VRM_PP_ARGCOUNT(__VA_ARGS__) \
    )(__VA_ARGS__)
```

```
IS_VALID(*_0)(int*)
```

...expands to...

```
is_valid(  
    [](auto _0) constexpr → decltype(*_0){})  
) (type_c<int*>)
```

...which is equivalent to...

```
std::is_callable<  
    decltype(  
        [](auto _0) constexpr → decltype(*_0){})  
    )(typename decltype(type_c<int*>)::type)  
>{}
```


This technique is very useful when combined with `if constexpr(...)` - it's a barebones *in-place* concept definition&check.

```
template <typename T0, typename T1>
auto some_generic_function(T0 a, T1 b)
{
    if constexpr(IS_VALID(foo(_0, _1))(T0, T1))
    {
        return foo(a, b);
    }
    else if constexpr(IS_VALID(_0 + _1)(T0, T1))
    {
        return a + b;
    }

    // ...
}
```

```
template <typename TC, typename T>
auto unify_legacy_api(TC& c, T x)
{
    if constexpr(IS_VALID(_0.erase(_1))(TC, T))
    {
        return c.erase(x);
    }
    else if constexpr(IS_VALID(_0.remove(_1))(TC, T))
    {
        return c.remove(x);
    }

    // ...
}
```

```
template <typename T>
auto poor_man_ufcs(T& x)
{
    if constexpr(IS_VALID(_0.foo())(T))
    {
        return x.foo();
    }
    else if constexpr(IS_VALID(foo(_0))(T))
    {
        return foo(x);
    }
}
```

Small caveat: it does not yet compile.

- `clang++` hasn't implemented support for `constexpr` lambdas yet.
- `g++` has, but there's a bug I found and reported (*as #78131*).

`IS_VALID` does work properly with `g++` trunk in other contexts where a *constant expression* is required though (e.g. *non-template context* `if constexpr(...)` and `static_assert`).

Thanks for your time!

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