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

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

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

```
template <typename T>
void pet(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>
    }
}
```

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

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

- C++11: `std::void_t` and `std::enable_if`.
- C++14: `boost::hana::is_valid` and `vrm::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**

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

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

```cpp
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?

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

...is equivalent to...

```cpp
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 `pet`.

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

template <typename T>
auto pet(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 `vrm::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**.

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

...is somewhat equivalent to...

```cpp
struct αиσиʏмσυƨ
{
    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`?

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

```cpp
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:

```cpp
[](auto&& x) -> decltype(x.meow()) { }
```

> How can we implement `is_callable`?

```cpp
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".

```cpp
template <typename T>
auto pet(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 `pet`.
- 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 `vrm::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*

```cpp
template <typename T>
auto pet(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.

```cpp
// 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...

```cpp
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**.

```cpp
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.

```cpp
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 pet(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
```

```cpp
#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 `vrm_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.

```cpp
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;
    }

    // ...
}
```

```cpp
template <typename TC, typename T>
auto unify_legacy_apis(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);
    }

    // ...
}
```

```cpp
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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https://github.com/SuperV1234/cpplondon