Variant: a type-safe union without undefined behavior (v2).

P0087R0, ISO/IEC JTC1 SC22 WG21

Axel Naumann (axel@cern.ch), 2015-09-28

Contents

Variant is the very spice of life,
That gives it all its flavor.
- William Cowper's "The Task", or actually a variant thereof

Introduction

C++ needs a type-safe union; here is a proposal. It attempts to apply the lessons learned from `optional` (1). It behaves as below:

```
variant<int, float> v, w;
v = 12;
int i = get<int>(v);
w = get<int>(v);
```

```
w = get<0>(v); // same effect as the previous line
w = v; // same effect as the previous line

get<double>(v); // ill formed
get<3>(v); // ill formed

try {
  get<float>(w); // will throw.
}
catch (bad_variant_access&) {}
```

It is a sibling of the proposal P0088 named “Variant: a type-safe union that is rarely invalid (v5)”. Background information and design discussion are available in P0086.

Version control

In principle, this proposal is is a revision of N4218, with lots of feedback incorporated. It shares (but ignores much of) the history of N4542, so please see there, too.

Discussion

Empty state and default construction

Default construction of a `variant` should be allowed, to increase usability for instance in containers. The invalid / empty state is an obvious choice. This makes the invalid state much more visible; it almost plays the role of an additional, implicit alternative.

Feature Test

No header called `variant` exists; testing for this header’s existence is thus sufficient.

Variant Objects

In general

Variant objects contain and manage the lifetime of a value. If the variant is valid, the single contained value’s type has to be one of the template argument types given to `variant`. These template arguments are called alternatives.

Changes to header `<tuple>`

`variant` employs the meta-programming facilities provided by the header `tuple`. It requires one additional facility:

```
static constexpr const size_t tuple_not_found = (size_t) -1;
template <class T, class U> class tuple_find;  // undefined
template <class T, class U> class tuple_find<T, const U>;
template <class T, class U> class tuple_find<T, volatile U>;
template <class T, class U> class tuple_find<T, const volatile U>;
template <class T, class... Types> class tuple_find<T, tuple<Types...>>;
template <class T, class T1, class T2> class tuple_find<T, pair<T1, T2>>;
template <class T, class... Types> class tuple_find<T, variant<Types...>>;
```

The *cv*-qualified versions behave as re-implementations of the non-*cv*-qualified version. The last versions are defined as

```
template <class T, class... Types>
class tuple_find<T, tuple<Types...>>:
  integral_constant<std::size_t, INDEX> {};

template <class T, class T1, class T2>
class tuple_find<T, pair<T1, T2>>:
  public tuple_find<T, tuple<T1, T2>> {};

template <class T, class... Types>
class tuple_find<T, variant<Types...>>:
  public tuple_find<T, tuple<Types...>> {};
```

where `INDEX` is the index of the first occurrence of T in `Types...` or `tuple_not_found` if the type does not occur. `tuple_find` is thus the inverse operation of `tuple_index`: for any tuple type `T` made up of different types, `tuple_index_t<tuple_find<U, T>::value>` is `U` for all of `T`'s parameter types.

Header `<variant>` synopsis

```
namespace std {
namespace experimental {
inline namespace fundamentals_vXXXX {
  // 2.?, variant of value types
  template <class... Types> class variant;
```

```
// 2.?, In-place construction
template <class T> struct emplaced_type_t{};
template <class T> constexpr emplaced_type_t<T> emplaced_type;

template <size_t I> struct emplaced_index_t{};
template <size_t I> constexpr emplaced_index_t<I> emplaced_index;

// 2.?, class bad_variant_access
class bad_variant_access;

// 2.?, tuple interface to class template variant
template <class T> class tuple_size;
template <size_t I, class T> class tuple_element;
template <class T, class... Types>
  struct tuple_size<variant<Types...>>;
template <size_t I, class... Types>
  struct tuple_element<I, variant<Types...>>;

// 2.?, value access
template <class T, class... Types>
  bool holds_alternative(const variant<Types...>&) noexcept;

template <class T, class... Types>
  remove_reference_t<T>& get(variant<Types...>&);
template <class T, class... Types>
  T&& get(variant<Types...>&&);
template <class T, class... Types>
  const remove_reference_t<T>& get(const variant<Types...>&);

template <size_t I, class... Types>
  remove_reference_t<tuple_element_t<I, variant<Types...>>>&
  get(variant<Types...>&);
template <size_t I, class... Types>
  tuple_element_t<I, variant<Types...>>&&
  get(variant<Types...>&&);
template <size_t I, class... Types>
  remove_reference_t<const tuple_element_t<I, variant<Types...>>>&
  get(const variant<Types...>&);

template <class T, class... Types>
  remove_reference_t<T>* get_if(variant<Types...>*);
template <class T, class... Types>
  const remove_reference_t<T>* get_if(const variant<Types...>*);

template <size_t I, class... Types>
```

```
    remove_reference_t<tuple_element_t<I, variant<Types...>>>*
    get_if(variant<Types...>*);
  template <size_t I, class... Types>
    const remove_reference_t<tuple_element_t<I, variant<Types...>>>*
    get_if(const variant<Types...>*);

  // 2.?, relational operators
  template <class... Types>
    bool operator==(const variant<Types...>&,
                    const variant<Types...>&);
  template <class... Types>
    bool operator!=(const variant<Types...>&,
                    const variant<Types...>&);
  template <class... Types>
    bool operator<(const variant<Types...>&,
                   const variant<Types...>&);
  template <class... Types>
    bool operator>(const variant<Types...>&,
                   const variant<Types...>&);
  template <class... Types>
    bool operator<=(const variant<Types...>&,
                    const variant<Types...>&);
  template <class... Types>
    bool operator>=(const variant<Types...>&,
                    const variant<Types...>&);

  // 2.?, Visitation
  template <class Visitor, class... Variants>
  decltype(auto) visit(Visitor&, Variants&...);

  template <class Visitor, class... Variants>
  decltype(auto) visit(const Visitor&, Variants&...);
} // namespace fundamentals_vXXXX
} // namespace experimental

  // 2.?, Hash support
  template <class T> struct hash;
  template <class... Types>
    struct hash<experimental::variant<Types...>>;
} // namespace std
```

Class template `variant`

```
namespace std {
namespace experimental {
```

```
inline namespace fundamentals_vXXXX {
  template <class... Types>
  class variant {
  public:

    // 2.? variant construction
    constexpr variant() noexcept;
    variant(const variant&) noexcept(see below);
    variant(variant&&) noexcept(see below);

    template <class T> constexpr variant(const T&);
    template <class T> constexpr variant(T&&);

    template <class T, class... Args>
      constexpr explicit variant(emplaced_type_t<T>, Args&&...);
    template <class T, class U, class... Args>
      constexpr explicit variant(emplaced_type_t<T>,
                                 initializer_list<U>,
                                 Args&&...);

    template <size_t I, class... Args>
      constexpr explicit variant(emplaced_index_t<I>, Args&&...);
    template <size_t I, class U, class... Args>
      constexpr explicit variant(emplaced_index_t<I>,
                                 initializer_list<U>,
                                 Args&&...);
    // 2.?, Destructor
    ~variant();

    // allocator-extended constructors
    template <class Alloc>
      variant(allocator_arg_t, const Alloc& a);
    template <class Alloc, class T>
      variant(allocator_arg_t, const Alloc& a, T);
    template <class Alloc>
      variant(allocator_arg_t, const Alloc& a, const variant&);
    template <class Alloc>
      variant(allocator_arg_t, const Alloc& a, variant&&);

    // 2.?, `variant` assignment
    variant& operator=(const variant&);
    variant& operator=(variant&&) noexcept(see below);


    template <class T> variant& operator=(const T&);
    template <class T> variant& operator=(const T&&) noexcept(see below);
```

```
    // 2.?, `variant` modifiers
    void clear() noexcept;

    template <class T, class... Args> void emplace(Args&&...);
    template <class T, class U, class... Args>
      void emplace(initializer_list<U>, Args&&...);
    template <size_t I, class... Args> void emplace(Args&&...);
    template <size_t I, class U, class... Args>
      void emplace(initializer_list<U>, Args&&...);

    // 2.?, value status
    bool valid() const noexcept;
    size_t index() const noexcept;

    // 2.?, variant swap
    void swap(variant&) noexcept(see below);

  private:
    static constexpr size_t max_alternative_sizeof
      = ...; // exposition only
    char storage[max_alternative_sizeof]; // exposition only
    size_t value_type_index; // exposition only
  };
} // namespace fundamentals_vXXXX
} // namespace experimental
} // namespace std
```

Any instance of `variant<Types...>` at any given time either contains a value of one of its template parameter `Types`, or is in an invalid state. When an instance of `variant<Types...>` contains a value of alternative type `T`, it means that an object of type `T`, referred to as the `variant<Types...>` object's contained value, is allocated within the storage of the `variant<Types...>` object. Implementations are not permitted to use additional storage, such as dynamic memory, to allocate its contained value. The contained value shall be allocated in a region of the `variant<Types...>` storage suitably aligned for all types in `Types`.

All types in `Types` shall be object types and shall satisfy the requirements of `Destructible` (Table 24).

Construction

For the default constructor, an exception is thrown if the first alternative type throws an exception. For all other `variant` constructors, an exception is thrown only if the construction of one of the types in `Types` throws an exception.

The copy and move constructor, respectively, of `variant` shall be a `constexpr` function if and only if all required element-wise initializations for copy and move, respectively, would satisfy the requirements for a `constexpr` function. The move and copy constructor of `variant<>` shall be `constexpr` functions.

In the descriptions that follow, let `i` be in the range `[0,sizeof...(Types))` in order, and `T_i` be the `i`th type in `Types`.

`constexpr variant() noexcept`

Effects: Constructs a `variant` in invalid state.
Postconditions: `valid()` is `false`.
Remarks: The expression inside `noexcept` is equivalent to `is_nothrow_default_constructible_v<T_0>`. The function shall not participate in overload resolution if `is_default_constructible_v<T_0>` is `false`.

`variant(const variant& w)`

Requires: `is_copy_constructible_v<T_i>` is `true` for all `i`.
Effects: initializes the `variant` to hold the same alternative as `w`. Initializes the contained value to a copy of the value contained by `w`.
Throws: Any exception thrown by the selected constructor of any `T_i` for all `i`.

`variant(variant&& w) noexcept(see below)`

Requires: `is_move_constructible_v<T_i>` is `true` for all `i`.
Effects: initializes the `variant` to hold the same alternative as `w`. Initializes the contained value with `std::forward<T_j>(get<j>(w))` with `j` being `w.index()`.
Throws: Any exception thrown by the selected constructor of any `T_i` for all `i`.
Remarks: The expression inside `noexcept` is equivalent to the logical AND of `is_nothrow_move_constructible<T_i>::value` for all `i`.

`template <class T> constexpr variant(const T& t)`

Requires: `is_copy_constructible_v<T>` is `true`.
Effects: initializes the `variant` to hold the alternative `T`. Initializes the contained value to a copy of `t`.
Postconditions: `holds_alternative<T>(*this)` is `true`
Throws: Any exception thrown by the selected constructor of T.
Remarks: The function shall not participate in overload resolution unless `T` is one of `Types...`. The function shall be `= delete` if there are multiple occurrences of `T` in `Types...`. If `T`'s selected constructor is a `constexpr` constructor, this constructor shall be a `constexpr` constructor.

```
template <class T> constexpr variant(T&& t)
```

Requires: is_move_constructible_v<T> is true.
Effects: initializes the variant to hold the alternative T. Initializes the contained value with std::forward<T>(t).
Postconditions: holds_alternative<T>(*this) is true
Throws: Any exception thrown by the selected constructor of T.
Remarks: The function shall not participate in overload resolution unless T is one of Types.... The function shall be = delete if there are multiple occurrences of T in Types.... If T's selected constructor is a constexpr constructor, this constructor shall be a constexpr constructor.

```
template <class T, class... Args> constexpr explicit variant(emplaced_type_t<T>,
Args&&...);
```

Requires: T is one of Types.... is_constructible_v<T, Args&&...> is true.
Effects: Initializes the contained value as if constructing an object of type T with the arguments std::forward<Args>(args)....
Postcondition: holds_alternative<T>(*this) is true
Throws: Any exception thrown by the selected constructor of T.
Remarks: The function shall be = delete if there are multiple occurrences of T in Types.... If T's selected constructor is a constexpr constructor, this constructor shall be a constexpr constructor.

```
template <class T, class U, class... Args> constexpr explicit
variant(emplaced_type_t<T>, initializer_list<U> il, Args&&...);
```

Requires: T is one of Types.... is_constructible<T, initializer_list<U>&, Args&&...>::value is true.
Effects: Initializes the contained value as if constructing an object of type T with the arguments il, std::forward<Args>(args)....
Postcondition: holds_alternative<T>(*this) is true
Remarks: The function shall be = delete if there are multiple occurrences of T in Types.... If T's selected constructor is a constexpr constructor, this constructor shall be a constexpr constructor.

```
template <size_t I, class... Args> constexpr explicit variant(emplaced_index_t<I>,
Args&&...);
```

Requires: I must be less than sizeof...(Types). is_constructible_v<tuple_element_t<I, variant>, Args&&...> is true.
Effects: Initializes the contained value as if constructing an object of type tuple_element_t<I, variant> with the arguments std::forward<Args>(args)....

Postcondition: `index()` is `I`
Throws: Any exception thrown by the selected constructor of `tuple_element_t<I, variant>`.
Remarks: If `tuple_element_t<I, variant>`'s selected constructor is a `constexpr` constructor, this constructor shall be a `constexpr` constructor.

```
template <size_t I, class U, class... Args> constexpr explicit
variant(emplaced_index_t<I>, initializer_list<U> il, Args&&...);
```

Requires: `I` must be less than `sizeof...(Types)`. `is_constructible_v<tuple_element_t<I, variant>, initializer_list<U>&, Args&&...>` is `true`.
Effects: Initializes the contained value as if constructing an object of type `tuple_element_t<I, variant>` with the arguments `il, std::forward<Args>(args)...`.
Postcondition: `index()` is `I`
Remarks: The function shall not participate in overload resolution unless `is_constructible_v<tuple_element_t<I, variant>, initializer_list<U>&, Args&&...>` is `true`. If `tuple_element_t<I, variant>`'s selected constructor is a `constexpr` constructor, this constructor shall be a `constexpr` constructor.

Destructor

```
~variant()
```

Effects: Behaves as if `clear()` is invoked.

Assignment

```
variant& operator=(const variant& rhs)
```

Requires: `is_copy_constructible_v<T_i> && is_copy_assignable_v<T_i>` is `true` for all `i`.
Effects: If `index() == rhs.index()`, calls `get<j>(*this) = get<j>(rhs)` with `j` being `index()`. Else copies the value contained in `rhs` to a temporary, then destructs the current contained value of `*this`. Sets `*this` to contain the same type as `rhs` and move-constructs the contained value from the temporary.
Returns: `*this`.
Postconditions: `index() == rhs.index()`
Exception safety: If an exception is thrown during the call to `T_i`'s copy constructor (with `i` being `rhs.index()`), `*this` will remain unchanged. If an exception is thrown during the call to `T_i`'s move constructor, `valid()`

will be `false` and no copy assignment will take place; the `variant` will be in a valid but partially unspecified state. If an exception is thrown during the call to `T_i`'s copy assignment, the state of the contained value is as defined by the exception safety guarantee of `T_i`'s copy assignment; `index()` will be `i`.

`variant& operator=(const variant&& rhs) noexcept(see below)`

Requires: `is_move_constructible_v<T_i> && is_move_assignable_v<T_i>` is `true` for all `i`.

Effects: If `valid() && index() == rhs.index()`, the move-assignment operator is called to set the contained object to `std::forward<T_j>(get<j>(rhs))` with `j` being `rhs.index()`. Else destructs the current contained value of `*this` if `valid()` is `true`, then initializes `*this` to hold the same alternative as `rhs` and initializes the contained value with `std::forward<T_j>(get<j>(rhs))`.

Returns: `*this`.

Remarks: The expression inside `noexcept` is equivalent to: `is_nothrow_move_assignable_v<T_i> && is_nothrow_move_constructible_v<T_i>` for all `i`.

Exception safety: If an exception is thrown during the call to `T_j`'s move constructor (with `j` being `rhs.index()`), `valid()` will be `false` and no move assignment will take place; the `variant` will be in a valid but partially unspecified state. If an exception is thrown during the call to `T_j`'s move assignment, the state of the contained value is as defined by the exception safety guarantee of `T_j`'s move assignment; `index()` will be `j`.

`template <class T> variant& operator=(const T& t)`

`template <class T> variant& operator=(const T&& t) noexcept(see below)`

Requires: The overload set `T_i(t)` of all constructors of all alternatives of this `variant` must resolve to exactly one best matching constructor call of an alternative type `T_j`, according to regular overload resolution; otherwise the program is ill-formed. [Note:

```
variant<string, string> v;
v = "abc";
```

is ill-formed, as both alternative types have an equally viable constructor for the argument.]

Effects: If `*this` holds a `T_j`, the copy / move assignment operator is called, passing `t`. Else, for the copy assignment and if `is_move_constructibe<T_j>` is `true`, creates a temporary of type `T_j`, passing `t` as argument to the selected constructor. Destructs the current contained value of `*this`, initializes `*this` to hold the alternative `T_j`, and initializes the contained value, for the move assignment by calling the selected constructor overload, passing `t`; for the copy-assignment by move-constructing the contained value from the temporary if `is_move_constructibe<T_j>` is `true`, and copy-constructing the contained value passing `t` if `is_move_constructibe<T_j>` is `false`.
Postcondition: `holds_alternative<T_j>(*this)` is `true`.
Returns: `*this`.
Exception safety: If an exception is thrown during the call to the selected constructor, `valid()` will be `false` and no copy / move assignment will take place. If an exception is thrown during the call to `T_j`'s copy / move assignment, the state of the contained value and `t` are as defined by the exception safety guarantee of `T_j`'s copy / move assignment; `valid()` will be `true`.
Remarks: The expression inside `noexcept` is equivalent to: `is_nothrow_move_assignable<T_i>::value && is_nothrow_move_constructible<T_i>::value` for all `i`.

Modifiers

`void clear() noexcept`

Effects: If `valid()` is `true`, calls `get<T_j>(*this).T_j::~T_j()` with `j` being `index()`
Postcondition: `valid()` is `false`.

`template <class T, class... Args> void emplace(Args&&...)`

Requires: `is_constructible_v<T, Args&&...>` is `true`.
Effects: Destructs the currently contained value if `valid()` is `true`. Then initializes the contained value as if constructing a value of type `T` with the arguments `std::forward<Args>(args)...`.
Postcondition: `holds_alternative<T>(*this)` is `true`.
Throws: Any exception thrown by the selected constructor of `T`.
Exception safety: If an exception is thrown during the call to `T`'s constructor, `valid()` will be `false`; the `variant` will be in a valid but partially unspecified state.

`template <class T, class U, class... Args> void emplace(initializer_list<U> il, Args&&...)`

Requires: `is_constructible_v<T, initializer_list<U>&, Args&&...>` is `true`.

Effects: Destructs the currently contained value if `valid()` is `true`. Then initializes the contained value as if constructing an object of type `T` with the arguments `il, std::forward<Args>(args)...`.

Postcondition: `holds_alternative<T>(*this)` is `true`

Throws: Any exception thrown by the selected constructor of `T`.

Exception safety: If an exception is thrown during the call to `T`'s constructor, `valid()` will be `false`; the `variant` will be in a valid but partially unspecified state.

Remarks: The function shall not participate in overload resolution unless `is_constructible<T, initializer_list<U>&, Args&&...>::value` is `true`.

`template <size_t I, class... Args> void emplace(Args&&...)`

Requires: `is_constructible_v<tuple_element<I, variant>, Args&&...>` is `true`.

Effects: Destructs the currently contained value if `valid()` is `true`. Then initializes the contained value as if constructing a value of type `tuple_element<I, variant>` with the arguments `std::forward<Args>(args)...`.

Postcondition: `index()` is `I`.

Throws: Any exception thrown by the selected constructor of `tuple_element<I, variant>`.

Exception safety: If an exception is thrown during the call to `tuple_element<I, variant>`'s constructor, `valid()` will be `false`; the `variant` will be in a valid but partially unspecified state.

`template <size_t I, class U, class... Args> void emplace(initializer_list<U> il, Args&&...)`

Requires: `is_constructible_v<tuple_element<I, variant>, initializer_list<U>&, Args&&...>` is `true`.

Effects: Destructs the currently contained value if `valid()` is `true`. Then initializes the contained value as if constructing an object of type `tuple_element<I, variant>` with the arguments `il, std::forward<Args>(args)...`.

Postcondition: `index()` is `I`

Throws: Any exception thrown by the selected constructor of `tuple_element<I, variant>`.

Exception safety: If an exception is thrown during the call to `tuple_element<I, variant>`'s constructor, `valid()` will be `false`; the `variant` will be in a valid but partially unspecified state.

Remarks: The function shall not participate in overload resolution unless `is_constructible_v<tuple_element<I, variant>, initializer_list<U>&, Args&&...>` is `true`.

`bool valid() const noexcept`

Effects: returns whether the `variant` contains a value (returns `true`), or is in a valid but partially unspecified state (returns `false`).

`size_t index() const noexcept`

Effects: Returns the index `j` of the currently active alternative, or `tuple_not_found` if `valid()` is `false`.

`void swap(variant& rhs) noexcept(see below)`

Requires: `valid() && rhs.valid()`. `is_move_constructible_v<T_i>` is `true` for all `i`.

Effects: if `index() == rhs.index()`, calls `swap(get<i>(*this), get<i>(hrs))` with `i` being `index()`. Else calls `swap(*this, hrs)`.

Throws: Any exceptions that the expression in the Effects clause throws.

Exception safety: If an exception is thrown during the call to function `swap(get<i>(*this), get<i>(hrs))`, the state of the value of `this` and of `rhs` is determined by the exception safety guarantee of `swap` for lvalues of `T_i` with `i` being `index()`. If an exception is thrown during the call to `swap(*this, hrs)`, the state of the value of `this` and of `rhs` is determined by the exception safety guarantee of `variant`'s move constructor and assignment operator.

In-place construction

```
template <class T> struct emplaced_type_t{};
template <class T> constexpr emplaced_type_t<T> emplaced_type{};
template <size_t I> struct emplaced_index_t{};
template <size_t I> constexpr emplaced_index_t<I> emplaced_index;
```

Template instances of `emplaced_type_t` are empty structure types used as unique types to disambiguate constructor and function overloading, and signaling (through the template parameter) the alternative to be constructed. Specifically, `variant<Types...>` has a constructor with `emplaced_type_t<T>` as the first argument followed by an argument pack; this indicates that `T` should be constructed in-place (as if by a call to a placement new expression) with the forwarded argument pack as parameters. If a `variant`'s `types` has multiple occurrences of `T`, `emplaces_index_t` must be used.

Template instances of `emplaced_index_t` are empty structure types used as unique types to disambiguate constructor and function overloading, and signaling (through the template parameter) the alternative to be constructed. Specifically, `variant<Types...>` has a constructor with `emplaced_index_t<I>` as the first argument followed by an argument pack; this indicates that `tuple_element<I, variant>` should be constructed in-place (as if by a call to a placement new expression) with the forwarded argument pack as parameters.

class bad_variant_access

```
class bad_variant_access : public logic_error {
public:
  explicit bad_variant_access(const string& what_arg);
  explicit bad_variant_access(const char* what_arg);
};
```

The class `bad_variant_access` defines the type of objects thrown as exceptions to report the situation where an attempt is made to access the value of a `variant` object through one of the `get` or `visit` overloads in an invalid way:

- for `get` overloads with template parameter list `size_t I, class... Types`, because `I` does not equal to `index()`,
- for `get` overloads with template parameter list `class T, class... Types`, because `holds_alternative<T>(v)` is `false`
- for `visit` overloads with any `variant` argument for which `valid()` is `false`

The value of `what_arg` of an exception thrown in these cases is implementation defined.

bad_variant_access(const string& what_arg)

Effects: Constructs an object of class `bad_variant_access`.

bad_variant_access(const char* what_arg)

Effects: Constructs an object of class `bad_variant_access`.

`tuple` interface to class template `variant`

```
template <class T, class... Types>    struct tuple_size <variant<Types...>>
```

```
template <class... Types>
class tuple_size<variant<Types...> >
  : public integral_constant<size_t, sizeof...(Types)> { };
```

```
template <size_t I, class... Types>    struct tuple_element<I,
variant<Types...>>
```

```
template <class... Types>
class tuple_element<variant<Types...> >
  : public tuple_element<I, tuple<Types...>> { };
```

Value access

```
template <class T, class... Types> bool holds_alternative(const
variant<Types...>& v) noexcept;
```

Requires: The type `T` occurs exactly once in `Types...`. Otherwise, the program is ill-formed.
Effects: returns `true` if `index()` is equal to `tuple_find<T, variant<Types...>>`.

```
template <class T, class... Types> remove_reference_t<T>& get(variant<Types...>&
v)
```

```
template <class T, class... Types> const remove_reference_t<T>&
get(const variant<Types...>&)
```

Requires: The type `T` occurs exactly once in `Types...`. Otherwise, the program is ill-formed.
Effects: Equivalent to `return get<tuple_find<T, variant<Types...>>::value>(v)`.
Throws: Any exceptions that the expression in the Effects clause throws.

```
template <class T, class... Types> T&& get(variant<Types...>&& v)
```

Requires: The type `T` occurs exactly once in `Types...`. Otherwise, the program is ill-formed.
Effects: Equivalent to `return get<tuple_find<T, variant<Types...>>::value>(v)`.
Throws: Any exceptions that the expression in the Effects clause throws.
Remarks: if the element type `T` is some reference type `X&`, the return type is `X&`, not `X&&`. However, if the element type is a non-reference type `T`, the return type is `T&&`.

```
template <size_t I, class... Types> remove_reference_t<T>& get(variant<Types...>&
v)
```

```
template <size_t I, class... Types> const remove_reference_t<T>&
get(const variant<Types...>& v)
```

Requires: The program is ill-formed unless `I < sizeof...(Types)`.
Effects: Return a (const) reference to the object stored in the variant, if `v.index()` is `I`, else throws an exception of type `bad_variant_access`.
Throws: An exception of type `bad_variant_access`.

```
template <size_t I, class... Types> T&& get(variant<Types...>&&
v)
```

Requires: The program is ill-formed unless `I < sizeof...(Types)`.
Effects: Equivalent to `return std::forward<typename tuple_element<I, variant<Types...> >::type&&>(get<I>(v))`.
Throws: Any exceptions that the expression in the Effects clause throws.
Remarks: if the element type `typename tuple_element<I, variant<Types...> >::type` is some reference type `X&`, the return type is `X&`, not `X&&`. However, if the element type is a non-reference type `T`, the return type is `T&&`.

```
template <class T, class... Types> remove_reference_t<T>* get(variant<Types...>*
v)
```

```
template <class T, class... Types> const remove_reference_t<T>*
get(const variant<Types...>* v)
```

Requires: The type `T` occurs exactly once in `Types...`. Otherwise, the program is ill-formed.
Effects: Equivalent to `return get<tuple_find<T, variant<Types...>>::value>(v)`.

```
template <size_t I, class... Types> remove_reference_t<tuple_element_t<I,
variant<Types...>>>* get(variant<Types...>*)
```

```
template <size_t I, class... Types> const remove_reference_t<tuple_element_t<I,
variant<Types...>>>* get(const variant<Types...>*)
```

Requires: The program is ill-formed unless `I < sizeof...(Types)`.
Effects: Return a (const) reference to the object stored in the variant, if `v->index()` is `I`, else returns `nullptr`.

Relational operators

```
template <class... Types> bool operator==(const variant<Types...>&
v, const variant<Types...>& w)
```

Requires: get<i>(v) == get<i>(w) is a valid expression returning a type that is convertible to bool, for for all i in 0 ... sizeof...(Types).

Returns: true if !v.valid() && !w.valid(). Otherwise, true if v.index() == w.index() && get<i>(v) == get<i>(w) with i being v.index(), otherwise false.

```
template <class... Types> bool operator!=(const variant<Types...>&
v, const variant<Types...>& w)
```

Returns: !(v == w).

```
template <class... Types> bool operator<(const variant<Types...>&
v, const variant<Types...>& w)
```

Requires: get<i>(v) < get<i>(w) is a valid expression returning a type that is convertible to bool, for for all i in 0 ... sizeof...(Types).

Returns: false if !v.valid() && !w.valid(). Otherwise, true if v.index() < w.index() || (v.index() == w.index() && get<i>(v) < get<i>(w)) with i being v.index(), otherwise false.

```
template <class... Types> bool operator>(const variant<Types...>&
v, const variant<Types...>& w)
```

Returns: w < v.

```
template <class... Types> bool operator<=(const variant<Types...>&
v, const variant<Types...>& w)
```

Returns: !(v > w).

```
template <class... Types> bool operator>=(const variant<Types...>&
v, const variant<Types...>& w)
```

Returns: !(v < w)

Visitation

```
template <class Visitor, class... Variants>   decltype(auto)
visit(Visitor& vis, Variants&... vars)
```

```
template <class Visitor, class... Variants> decltype(auto) visit(const
Visitor& vis, const Variants&... vars)
```

Requires: The expression in the Effects clause must be a valid expression of the same type, for all combinations of alternative types of all variants.

Effects: Calls vis(get<T_0_i>(get<0>(vars)),get<T_1_i>(get<1>(vars),..) with T_j_i being get<j>(vars).index().

Throws: If var.valid() is false for any var in vars, throws an exception of type bad_variant_access.

Remarks: visit with sizeof...(Variants) being 0 is ill-formed. For sizeof...(Variants) being 1, the invocation of the callable must be implemented in O(1), i.e. it must must not depend on sizeof...(Types). For sizeof...(Variants) greater 1, the invocation of the callable has no complexity requirements.

Hash support

```
template <class... Types> struct hash<experimental::variant<Types...>>
```

Requires: the template specialization hash<T_i> shall meet the requirements of class template hash (C++11 §20.8.12) for all i. The template specialization hash<variant<Types...>> shall meet the requirements of class template hash.

Conclusion

A variant has proven to be a useful tool. This paper proposes the necessary ingredients.

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References

1. *Working Draft, Technical Specification on C++ Extensions for Library Fundamentals.* N4335