C++ONLINE

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TALK:

JSON IN C++

DESIGNING A TYPE FOR WORKING WITH JSON VALUES

2025

JSON in C++:

designing a type for working with JSON values

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𝕏 @cpp_ape

- quick overview of JSON
- design for a C++ type for working with JSON values
  - standard containers, `std::variant`
- C++ allocator support

Plan for this talk

Constraints for the implementation:

- use C++17
- write as little code as possible
  (while maintaining reasonable design and performance)

Not in this talk:

- JSON string escaping
- serialization/stringification
- parsing

Constraints for this talk

Douglas Crockford specified JSON in the early 2000s.

RFC 8259

`null`	null	primitive types or scalar types
`true` or `false`	Boolean	
`3.14`	number	
`"hello"`	string	
`[ 1, 2, 3 ]`	array (sequence)	structured types or collection types
`{ "key": "value" }`	object (dictionary)	

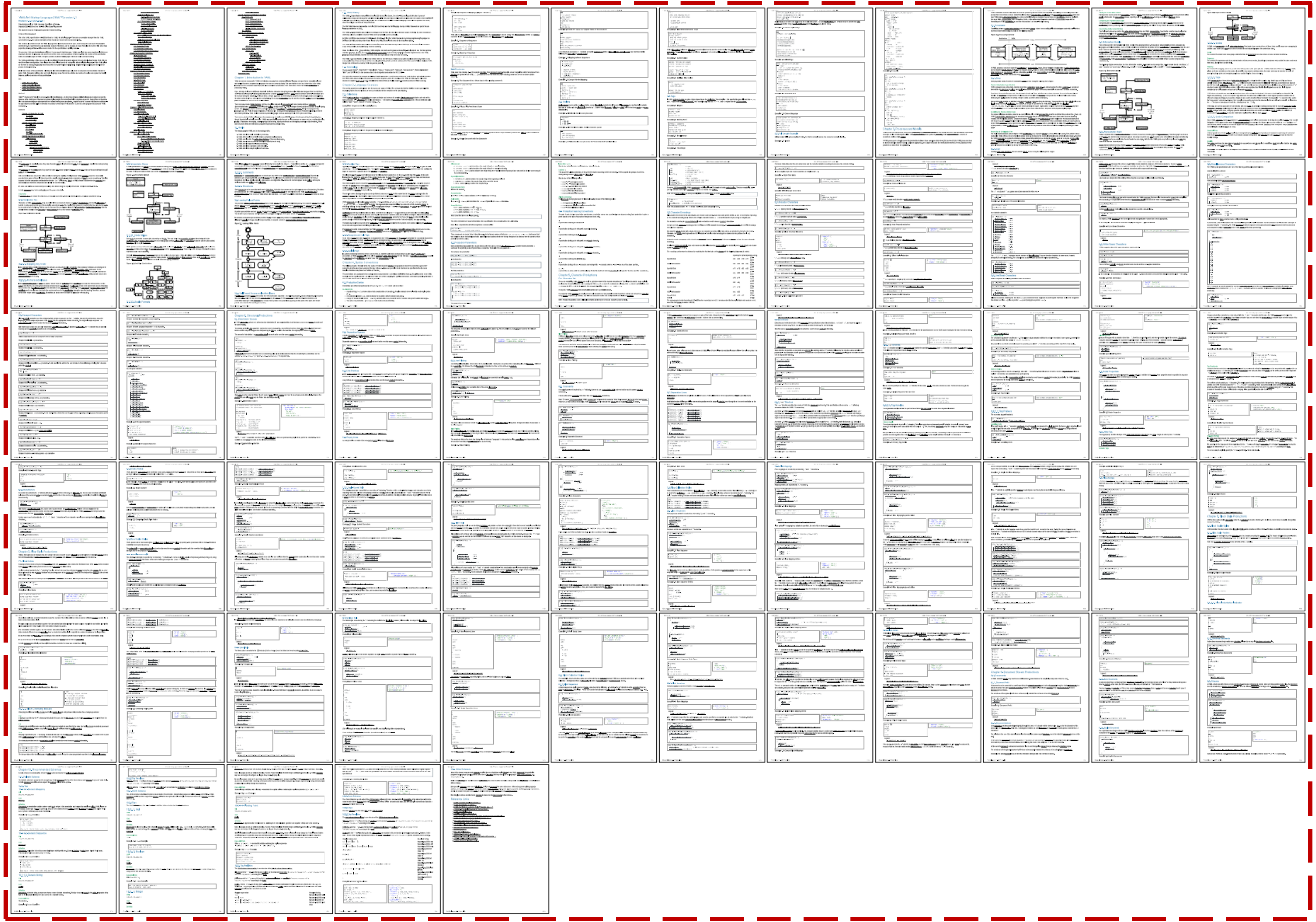
Overview of JSON

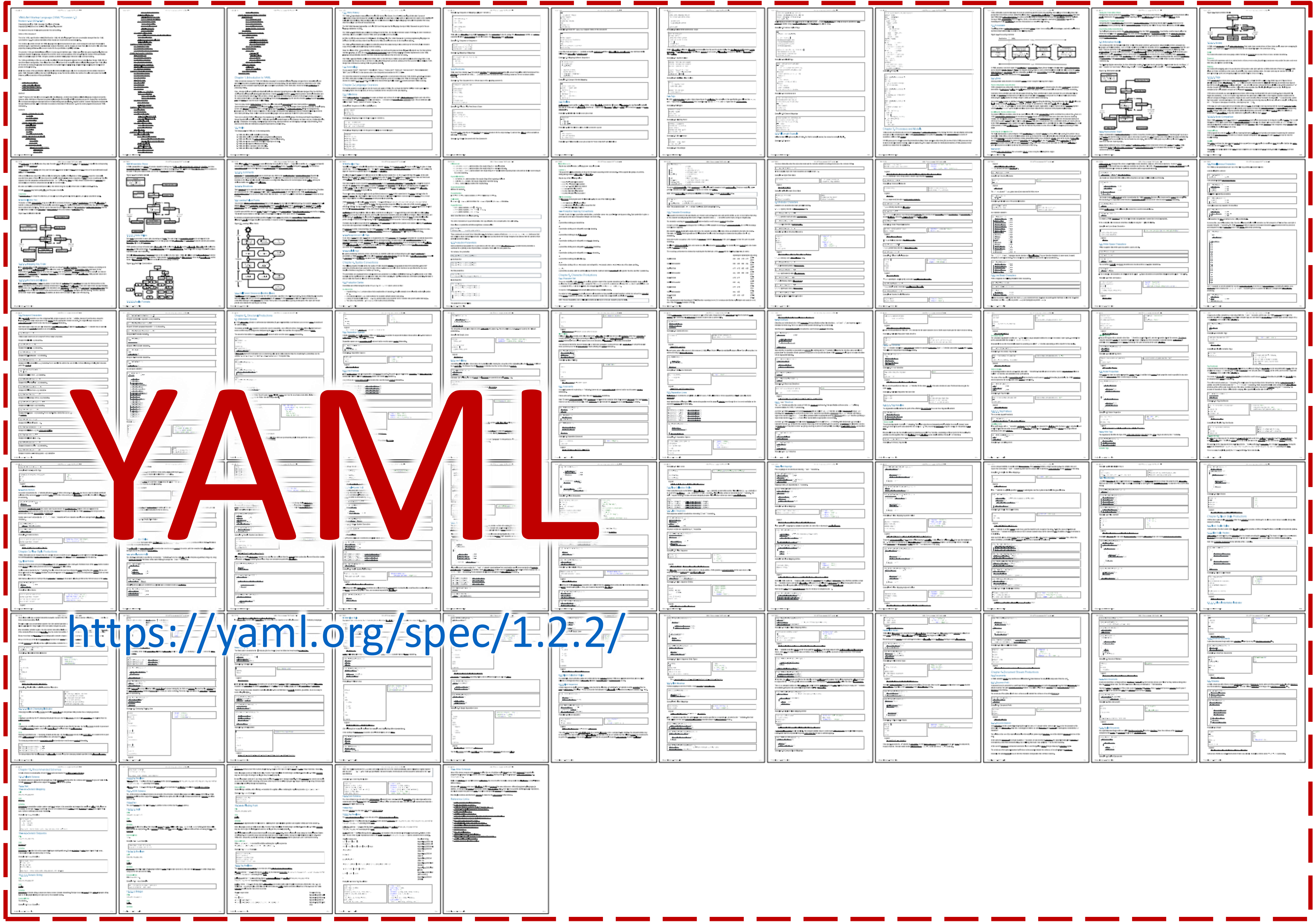
JSON grammar defined by RFC 8259

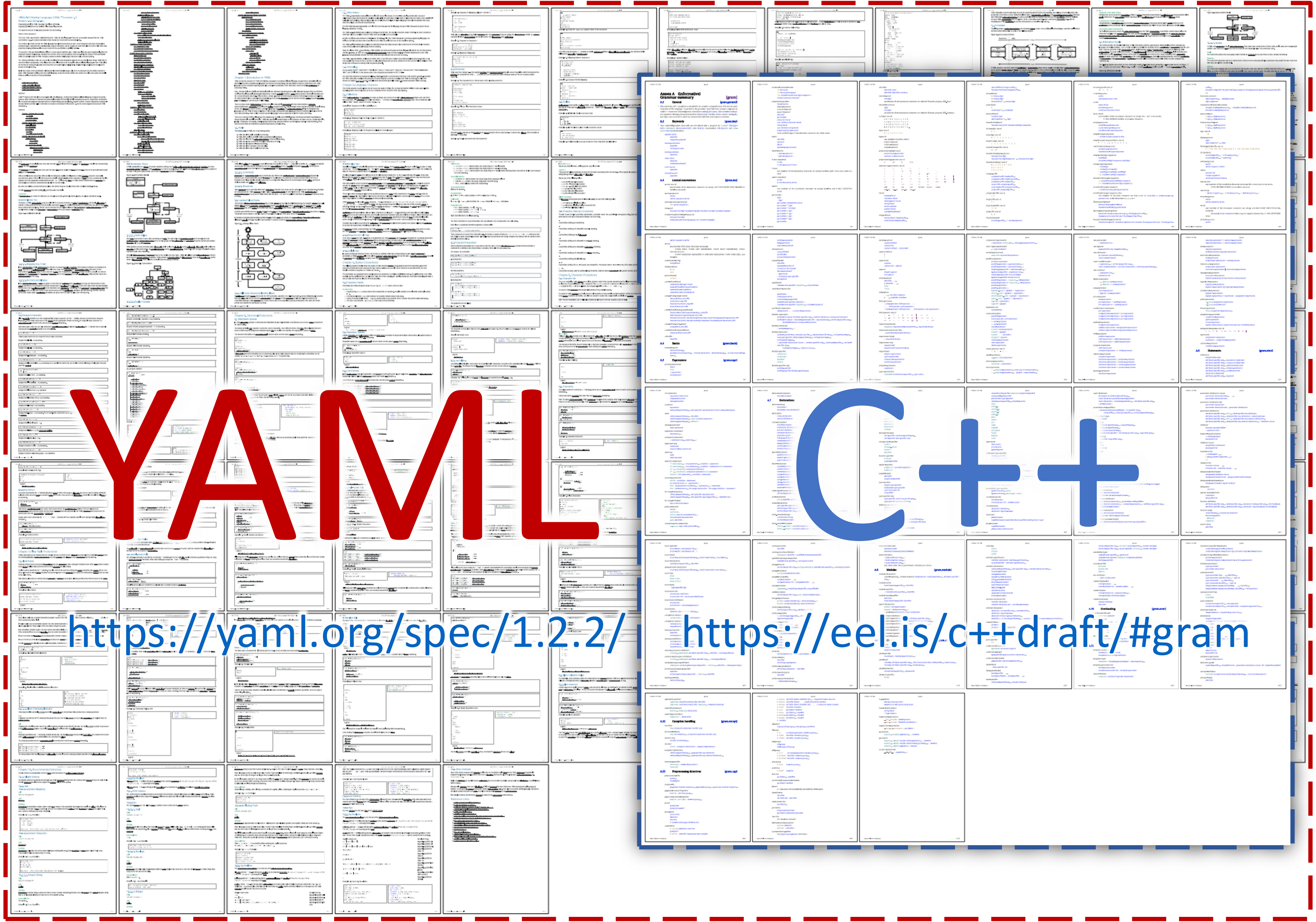
```
JSON-text = ws value ws
begin-array     = ws %x5B ws  ; [ left square bracket
begin-object    = ws %x7B ws  ; { left curly bracket
end-array       = ws %x5D ws  ; ] right square bracket
end-object      = ws %x7D ws  ; } right curly bracket
name-separator  = ws %x3A ws  ; : colon
value-separator = ws %x2C ws  ; , comma
ws = *(
        %x20 /              ; Space
        %x09 /              ; Horizontal tab
        %x0A /              ; Line feed or New line
        %x0D )              ; Carriage return
value = false / null / true / object / array / number / string
false = %x66.61.6c.73.65   ; false
null  = %x6e.75.6c.6c      ; null
true  = %x74.72.75.65      ; true
object = begin-object [ member *( value-separator member ) ]
         end-object
member = string name-separator value
array = begin-array [ value *( value-separator value ) ] end-array
```

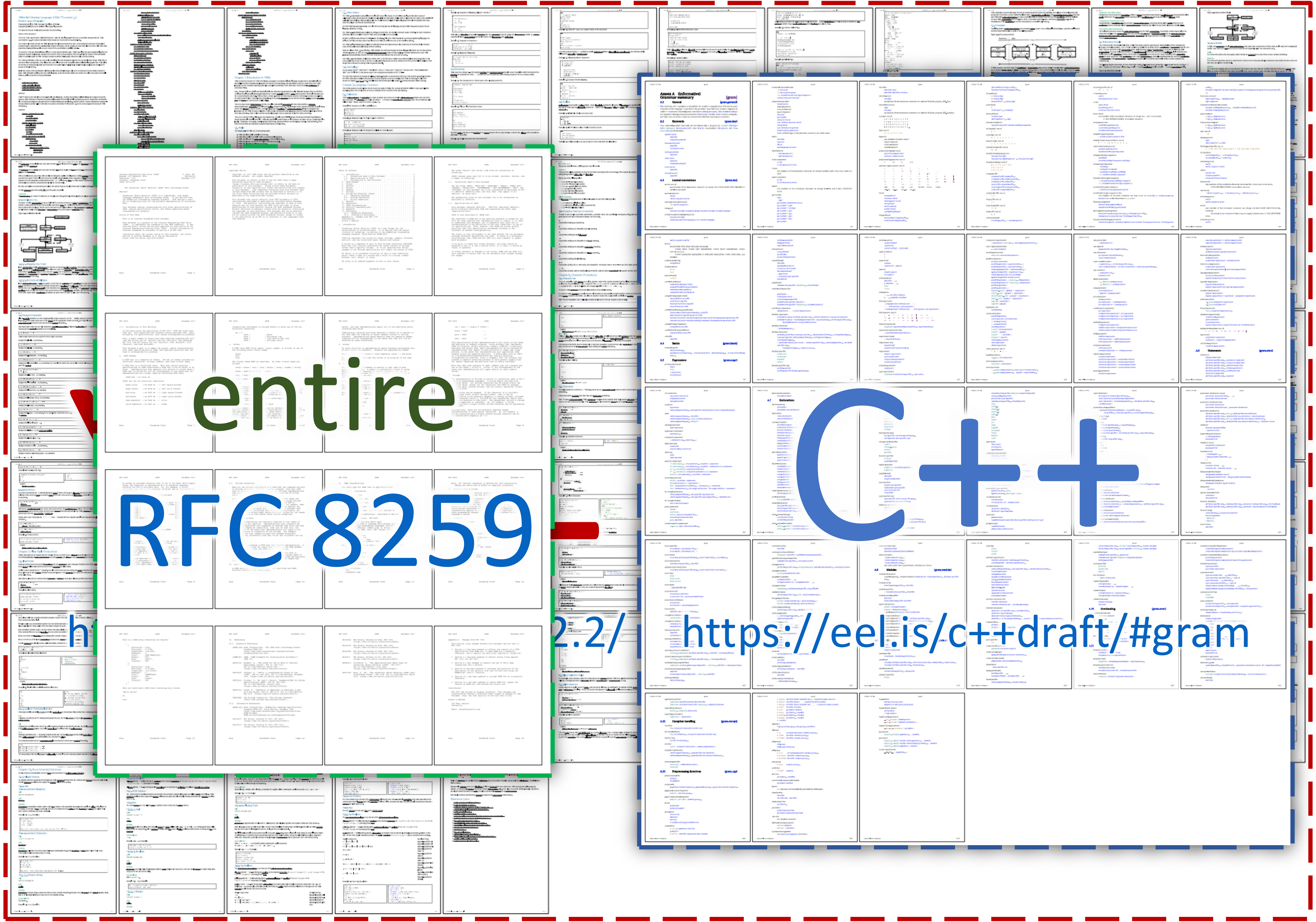
```
number = [ minus ] int [ frac ] [ exp ]
decimal-point = %x2E       ; .
digit1-9 = %x31-39         ; 1-9
e = %x65 / %x45            ; e E
exp = e [ minus / plus ] 1*DIGIT
frac = decimal-point 1*DIGIT
int = zero / ( digit1-9 *DIGIT )
minus = %x2D               ; -
plus = %x2B                ; +
zero = %x30                ; 0
string = quotation-mark *char quotation-mark
char = unescaped /
    escape (
        %x22 /          ; "    quotation mark  U+0022
        %x5C /          ; \    reverse solidus U+005C
        %x2F /          ; /    solidus         U+002F
        %x62 /          ; b    backspace       U+0008
        %x66 /          ; f    form feed       U+000C
        %x6E /          ; n    line feed       U+000A
        %x72 /          ; r    carriage return U+000D
        %x74 /          ; t    tab             U+0009
        %x75 4HEXDIG )  ; uXXXX                U+XXXX
escape = %x5C              ; \
quotation-mark = %x22      ; "
unescaped = %x20-21 / %x23-5B / %x5D-10FFFF
```

Overview of JSON




YAML
https://yaml.org/spec/1.2.2/


YAML
https://yaml.org/spec/1.2.2/
C++
https://eel.is/c++draft/#gram


entire
RFC8259
C++
https://eel.is/c++draft/#gram

JSON		C++
null	null	
Boolean	true or false	bool
number	3.14	int64_t, double
string	"hello"	std::string
array	[1, 2, 3]	std::vector<Value>
object	{ "key": "value" }	std::unordered_map<std::string, Value>

keys are unordered

Mapping of JSON types into C++

C++17:

`char` — ~~(usually)~~ 8 bit integer type

```
namespace std {
  using string = basic_string<char, char_traits<char>, allocator<char>>;
}
```

C++20:

`char8_t` — (at least) 8 bit integer type able to accommodate UTF-8 code units

```
namespace std {
  using u8string = basic_string<char8_t, char_traits<char8_t>, allocator<char8_t>>;
}
```

What about interoperability between `std::string` and `std::u8string`? 🤷‍♀️

Mapping of JSON types into C++

JSON value is a union type

```
std::variant<std::monostate,   ← null
             bool,
             int64_t,
             double,
             std::string,              struct Value;
             std::vector<Value>,
             std::unordered_map<String, Value>>
```

Mapping of JSON types into C++

```cpp
struct Value {
  using Null    = std::monostate;
  using Boolean = bool;
  using String  = std::string;
  using Array   = std::vector<Value>;
  using Object  = std::unordered_map<String, Value>;
  using Variant =
    std::variant<Null, Boolean, int64_t, double, String, Array, Object>;
  //...
private:
  //...
  Variant m_data;
};
```

Value type

```
Value v; // default ctor

Value boolean = true;
Value string = "hello";
Value number = 42;
```

`Value` type

```
struct Value {
  //...
  Value() = default;

  template<typename T,
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, int> = 0>
  Value(T &&v) noexcept(std::is_nothrow_constructible_v<Variant, T&&>) :
    m_data{ std::forward<T>(v) }
  {}

  Value(std::string_view s) :
    m_data{ std::in_place_type<String>, s }
  {}

  //...
};
```

```
struct Value {
  //...
  Value() = default;

  template<typename T,
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, int> = 0>
  Val                 pt(std::is_nothrow_constructible_v<Variant, T&&>) :
    m                 ard<T>(v) }
  {}

  Value(std::string_view s) :
    m_data{ std::in_place_type<String>, s }
  {}

  //...
};
```

safe to put into
template paremeters

```
struct Value {
namespace detail {
  template<typename T>
  using RemoveCVRef = std::remove_cv_t<std::remove_reference_t<T>>;
}
  template<typename T,
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, int> = 0>
  Value(T &&v) noexcept(std::is_nothrow_constructible_v<Variant, T&&>) :
    m_data{ std::forward<T>(v) }
  {}

  Value(std::string_view s) :
    m_data{ std::in_place_type<String>, s }
  {}

  //...
};
```

```
struct Value {
  //...
  Value() = default;

  template<typename T>
    requires         (!std::is_same_v<std::remove_cvref_t<T>, Value> &&
                      std::is_convertible_v<T&&, Variant>)
  Value(T &&v) noexcept(std::is_nothrow_constructible_v<Variant, T&&>) :
    m_data{ std::forward<T>(v) }
  {}

  Value(std::string_view s) :
    m_data{ std::in_place_type<String>, s }
  {}

  //...
};
```

```
struct Value {
  //...
  Value() = default;

  template<typename T>
    requires        (!std::is_same_v<std::remove_cvref_t<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>)
  Value(T &&v) noexcept(std::is_nothrow_constructible_v<Variant, T&&>) :
    m_data{ std::forward<T>(v) }
  {}

  Value(std::string_view s) :
    m_data{ std::in_place_type<String>, s }
  {}

  //...
};
```

```
struct Value {
  //...
  Value() = default;

  template<typename T>
    requires          (!std::is_same_v<std::remove_cvref_t<T>, Value> &&
                       std::is_convertible_v<T&&, Variant>)
  Value(T &&v) noexcept(std::is_nothrow_constructible_v<Variant, T&&>) :
    m_data{ std::forward<T>(v) }
  {}

  Value(std::string_view s) :
    m_data{ std::in_place_type<String>, s }
  {}

  //...
};
```

```
struct Value {
  //...
  template<typename T>
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, Value>
  Value &operator=(T &&v)
    noexcept  ...throw_assignable_v<Variant, T&&>) {
    variant(  ...rward<T>(v);
    return *this;
  }

  Value &operator=(std::string_view s) {
    variant().template emplace<String>(s);
    return *this;
  }
  //...
};
```

need to be
the return type

```
struct Value {
  //...
  template<typename T,
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, int> = 0>
  Value &operator=(T &&v)
    noexcept(std::is_nothrow_assignable_v<Variant, T&&>);
  //...
};

Value v;
v.operator=<bool, 0>(true);
v.operator=<bool, 1>(true);
v.operator=<bool, 2>(true);
v.operator=<bool, 3>(true);
v.operator=<bool, 4>(true);
```

```cpp
struct Value {
  //...
  template<typename T>
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, Value>
      &operator=(T &&v)
    noexcept(std::is_nothrow_assignable_v<Variant, T&&>) {
    variant() = std::forward<T>(v);
    return *this;
  }

  Value &operator=(std::string_view s) {
    variant().template emplace<String>(s);
    return *this;
  }
  //...
};
```

```
struct Value {
  //...
  template<typename T>
    requires          (!std::is_same_v<std::remove_cvref_t<T>, Value> &&
                       std::is_convertible_v<T&&, Variant>)
  Value &operator=(T &&v)
    noexcept(std::is_nothrow_assignable_v<Variant, T&&>) {
    variant() = std::forward<T>(v);
    return *this;
  }

  Value &operator=(std::string_view s) {
    variant().template emplace<String>(s);
    return *this;
  }
  //...
};
```

```
struct Value {
  //...
  template<typename T>
    requires          (!std::is_same_v<std::remove_cvref_t<T>, Value> &&
                       std::is_convertible_v<T&&, Variant>)
  Value &operator=(T &&v)
    noexcept(std::is_nothrow_assignable_v<Variant, T&&>) {
    variant() = std::forward<T>(v);
    return *this;
  }

  Value &operator=(std::string_view s) {
    variant().template emplace<String>(s);
    return *this;
  }
  //...
};
```

C++20


```
struct Value {
  //...
  template<typename T>
    requires         (!std::is_same_v<std::remove_cvref_t<T>, Value> &&
                      std::is_convertible_v<T&&, Variant>)
  Value &operator=(T &&v)
    noexcept(std::is_nothrow_assignable_v<Variant, T&&>) {
    variant() = std::forward<T>(v);
    return *this;
  }

  Value &operator=(std::string_view s) {
    variant().template emplace<String>(s);
    return *this;
  }
  //...
};
```

```
struct Value {
  //...
  Value() = default;
  template<typename T,
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>
  Value(T &&v) noexcept(std::is_nothrow_constructible_v<Variant, T&&>);
  Value(std::string_view s);
  template<typename T>
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, Value>
  Value &operator=(T &&v);
  Value &operator=(std::string_view s);


  //...
};
```

Which rule?

- rule of three
- rule of five
- rule of zero

```
struct Value {
  //...
  Value() = default;
  template<typename T,
    std::enable_if_t<!std::is_same_v<                  Ref<T>, Value> &&
                     std::is_converti                  nt>
  Value(T &&v) noexcept(std::is_nothr                  _v<Variant, T&&>);
  Value(std::string_view s);
  template<typename T>
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, Value>
  Value &operator=(T &&v);
  Value &operator=(std::string_view s);


  //...
};
```

Which rule?

destructor
copy constructor
copy assignment
move constructor
move assignment
none of the above

rule of three

rule of five

rule of zero

```
struct Value {
  //...
  Value() = default;
  template<typename T,
    std::enable_if_t<!std::is_same_v<          Ref<T>, Value> &&
                     std::is_converti           nt>
  Value(T &&v) noexcept(std::is_nothr           _v<Variant, T&&>);
  Value(std::string_view s);
  template<typename T>
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, Value>
  Value &operator=(T &&v);
  Value &operator=(std::string_view s);


  //...
};
```

Which rule?

- destructor
- copy constructor
- copy assignment
- move constructor
- move assignment
- none of the above

rule of three (destructor, copy constructor, copy assignment)

rule of five (destructor, copy constructor, copy assignment, move constructor, move assignment)

rule of zero (none of the above)

```
struct Value {
  //...
  friend bool operator==(const Value &a, const Value &b) {
    return a.variant() == b.variant();
  }
  friend bool operator!=(const Value &a, const Value &b) {
    return a.variant() != b.variant();
  }






  //...
};
```

C++20


```
struct Value {
  //...
  friend bool operator==(const Value&, const Value&) = default;

  //...
};
```

`operator!=` is synthesized from `operator==`

```
struct Value {
  //...
  [[nodiscard]] const Variant &variant() const& noexcept { return m_data; }
  [[nodiscard]] Variant &variant() & noexcept { return m_data; }
  [[nodiscard]] Variant &&variant() && noexcept {
    return std::move(m_data);
  }
  [[nodiscard]] const Variant &&variant() const&& noexcept {
    return std::move(m_data);
  }
  operator const Variant&() const& noexcept { return m_data; }
  operator Variant&() & noexcept { return m_data; }
  operator Variant&&() && noexcept { return std::move(m_data); }
  operator const Variant&&() const&& noexcept { return std::move(m_data); }

  //...
};
```

```
struct Value {
  //...
  [[nodiscard]] const Variant &variant() const& noexcept { return m_data; }
  [[nodiscard]] Variant &variant() & noexcept { return m_data; }
  [[nodiscard]] Variant &&variant() && noexcept {
    return std::move(m_data);
  }
  [[nodiscard]] const Variant &&variant() const&& noexcept {
    return std::move(m_data);
  }
  operator const Variant&() const& noexcept { return m_data; }
  operator Variant&() & noexcept { return m_data; }
  operator Variant&&() && noexcept { return std::move(m_data); }
  operator const Variant&&() const&& noexcept { return std::move(m_data); }

  //...
};
```

```
struct Value {
  //...
  [[nodiscard]] const Variant &variant() const& noexcept { return m_data; }
  [[nodiscard]] Variant &variant() & noexcept { return m_data; }
  [[nodiscard]] Variant &&variant() && noexcept {
    return std::move(m_data);
  }
  [[nodiscard]] const Variant &&variant() const&& noexcept {
    return std::move(m_data);
  }
  operator const Variant&() const& noexcept { return m_data; }
  operator Variant&() & noexcept { return m_data; }
  operator Variant&&() && noexcept { return std::move(m_data); }
  operator const Variant&&() const&& noexcept { return std::move(m_data); }

  //...
};
```

```
using Object  = Value::Object;
using Array   = Value::Array;
using String  = Value::String;
using Boolean = bool;
using Null    = std::monostate;
using Variant = Value::Variant;
```

Value type

```cpp
void print(const Value &value) {
  std::visit(Overloaded{
    [](Null) { std::cout << "null"; },
    [](bool b) { std::cout << "boolean: " << (b ? "true" : "false"); },
    [](int64_t i) { std::cout << "integer: " << i; },
    [](double d) { std::cout << "decimal: " << d; },
    [](const std::string &s) { std::cout << "string: " << s; },
    [](const Array&) { std::cout << "array"; },
    [](const Object&) { std::cout << "object"; }
  }, value.variant());
  std::cout << '\n';
}
```

Value type

```
void print(const Value &value) {
  std::visit(Overloaded{
    [](Null) { std::cout << "null"; },
    [](bool b) { std::cout << "boolean: " << (b ? "true" : "false"); },
    [](
    [](
    [](
    [](const Array&) { std::cout << "array"; },
    [](const Object&) { std::cout << "object"; }
  }, value.variant());
  std::cout << '\n';
}
```

```
template<typename... F>
struct Overloaded : F... { using F::operator()...; };
template<typename... F>
Overloaded(F...) -> Overloaded<F...>; // needed until C++20
```

Value type

```cpp
void print(const Value &value) {
  std::visit(Overloaded{
    [](Null) { std::cout << "null"; },
    [](bool b) { std::cout << "boolean: " << (b ? "true" : "false"); },
    [](int64_t i) { std::cout << "integer: " << i; },
    [](double d) { std::cout << "decimal: " << d; },
    [](const std::string &s) { std::cout << "string: " << s; },
    [](const Array&) { std::cout << "array"; },
    [](const Object&) { std::cout << "object"; }
  }, value.variant());
  std::cout << '\n';
}
```

Value type

```
Value boolean = true;
print(boolean);
```

output:

Clang 18 -std=c++17

```
boolean: true
```

MSVC (VS 2022) -std:c++17

```
boolean: true
```

`Value` type

```
Value string = "hello";
print(string);
```

output:

Clang 18 -std=c++17

```
string: hello
```

MSVC (VS 2022) -std:c++17

```
boolean: true
```

`Value` type

```
Value number = 42;
print(number);
```

output:

Clang 18 -std=c++17

```
integer: 42
```

MSVC (VS 2022) -std:c++17

error : no viable conversion from 'int' to 'Value'

`Value` type

In C++17 variant alternative is chosen as if by overload resolution:

```
void test(std::monostate); // Null
void test(bool); // Boolean
void test(int64_t); // integer
void test(double); // decimal
void test(std::string); // String
void test(std::vector<Value>); // Array
void test(std::unordered_map<String, Value>) // Object

test(true);    // calls test(bool)
test("hello"); // calls test(bool)
test(42);      // error : call to 'test' is ambiguous
```

This nonsense is fixed in P0608.
MS left the original behavior in
-std=c++17 mode
for backwards compatibility.

```
#if defined(_MSC_VER) && \
    (defined(_MSVC_LANG) && _MSVC_LANG > __cplusplus && \
     _MSVC_LANG == 201703L || __cplusplus == 201703L)
#define NEED_WORKAROUND_FOR_UNIMPLEMENTED_P0608
#endif
```

`Value` type

Microsoft made P0608 behavior unconditional in -std=c++17 mode in VS 2022 17.12 release.

```
#if defined(_MSC_VER) && _MSVC_STL_UPDATE < 202408L && \
    (defined(_MSVC_LANG) && _MSVC_LANG > __cplusplus && \
     _MSVC_LANG == 201703L || __cplusplus == 201703L)
#define NEED_WORKAROUND_FOR_UNIMPLEMENTED_P0608
#endif
```

`Value` type

```
struct Value {
  //...
  Value() = default;
  template<typename T,
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>, int> = 0>
  Value(T &&v) noexcept(std::is_nothrow_constructible_v<Variant, T&&>);
  Value(std::string_view s);
#if defined(NEED_WORKAROUND_FOR_UNIMPLEMENTED_P0608)
  Value(const char *s) : m_data{ std::in_place_type<String>, s } {}
  Value(int i) noexcept : m_data{ std::in_place_type<int64_t>, i } {}
#endif




  //...
};
```

```
  //...
  template<typename T>
    std::enable_if_t<!std::is_same_v<detail::RemoveCVRef<T>, Value> &&
                     std::is_convertible_v<T&&, Variant>,
  Value> &operator=(T &&v);
  Value &operator=(std::string_view s);
#if defined(NEED_WORKAROUND_FOR_UNIMPLEMENTED_P0608)
  Value &operator=(const char *s) {
    variant().template emplace<String>(s);
    return *this;
  }
  Value &operator=(int i) noexcept {
    variant().template emplace<int64_t>(i);
    return *this;
  }
#endif
  //...
```

output:

```
Value boolean = true;
print(boolean);
```

```
boolean: true
```

```
Value string = "hello";
print(string);
```

```
string: hello
```

```
Value number = 42;
print(number);
```

```
integer: 42
```

`Value` type

```cpp
using json = nlohmann::json;

json j2 = {
  {"pi", 3.141},
  {"happy", true},
  {"name", "Niels"},
  {"nothing", nullptr},
  {"answer", {
    {"everything", 42}
  }},
  {"list", {1, 0, 2}},
  {"object", {
    {"currency", "USD"},
    {"value", 42.99}
  }}
};
```

```
json x = {
  {}
};

std::cout << x.dump(2) << '\n';
```

outputs:

```
[
  null
]
```

```
json x = {
  { "value" }
};

std::cout << x.dump(2) << '\n';
```

outputs:

```
[
  [
    "value"
  ]
]
```

```cpp
json x = {
  { "key?", "value?" }
};

std::cout << x.dump(2) << '\n';
```

outputs:

```
{
  "key?": "value?"
}
```

```
json x = {
  { "key?", "value?", "oops" }
};

std::cout << x.dump(2) << '\n';
```

outputs:

```
[
  [
    "key?",
    "value?",
    "oops"
  ]
]
```

```
Value json = Object{
  { "null", Null{} },
  { "boolean", true },
  { "integer", 42 },
  { "decimal", 3.14 },
  { "string", "hello" },
  { "array", Array{
    1, 2, 3
  } },
  { "nested object", Object{
    { "foo", "bar" }
  } }
};
```

`std::unordered_map<String, Value>`

`std::vector<Value>`

Value type

```
struct Value {
  //...
  [[nodiscard]] bool isObject() const noexcept {
    return std::holds_alternative<Object>(variant());
  }
  [[nodiscard]] const Object &asObject() const& {
    return std::get<Object>(variant());
  }
  [[nodiscard]] Object &asObject() & {
    return std::get<Object>(variant());
  }
  [[nodiscard]] Object &&asObject() && {
    return std::move(std::get<Object>(variant()));
  }

  //...
};
```

```cpp
struct Value {
  //...
  [[nodiscard]] bool isArray() const noexcept {
    return std::holds_alternative<Array>(variant());
  }
  [[nodiscard]] const Array &asArray() const& {
    return std::get<Array>(variant());
  }
  [[nodiscard]] Array &asArray() & {
    return std::get<Array>(variant());
  }
  [[nodiscard]] Array &&asArray() && {
    return std::move(std::get<Array>(variant()));
  }

  //...
};
```

```cpp
struct Value {
  //...
  [[nodiscard]] bool isString() const noexcept {
    return std::holds_alternative<String>(variant());
  }
  [[nodiscard]] const String &asString() const& {
    return std::get<String>(variant());
  }
  [[nodiscard]] String &asString() & {
    return std::get<String>(variant());
  }
  [[nodiscard]] String &&asString() && {
    return std::move(std::get<String>(variant()));
  }

  //...
};
```

```
struct Value {
  //...
  [[nodiscard]] bool isDouble() const noexcept {
    return std::holds_alternative<double>(variant());
  }
  [[nodiscard]] double asDouble() const {
    return std::get<double>(variant());
  }
  [[nodiscard]] double &asDouble() {
    return std::get<double>(variant());
  }





  //...
};
```

```
struct Value {
  //...
  [[nodiscard]] bool isInt() const noexcept {
    return std::holds_alternative<int64_t>(variant());
  }
  [[nodiscard]] int64_t asInt() const {
    return std::get<int64_t>(variant());
  }
  [[nodiscard]] int64_t &asInt() {
    return std::get<int64_t>(variant());
  }




  //...
};
```

```cpp
struct Value {
  //...
  [[nodiscard]] bool isBool() const noexcept {
    return std::holds_alternative<Boolean>(variant());
  }
  [[nodiscard]] Boolean asBool() const {
    return std::get<Boolean>(variant());
  }
  [[nodiscard]] Boolean &asBool() {
    return std::get<Boolean>(variant());
  }




  //...
};
```

```
struct Value {
  //...
  [[nodiscard]] bool isNull() const noexcept {
    return std::holds_alternative<Null>(variant());
  }









  //...
};
```

```
Value json = Object{
  //...
};

assert(json.isObject());
auto &object = json.asObject();

assert(object["array"].isArray());
auto &array = object["array"].asArray();
array[0]; // can do whatever std::vector allows

assert(object["nested object"].isObject());
auto &nested = object["nested object"].asObject();
nested["foo"]; // can do whatever std::unordered_map allows
```

Value type

```cpp
using json = nlohmann::json;

json j2 = {
  //...
  {"list", {1, 0, 2}},
  //...
};

j2["list"][0];
```

```cpp
using json = nlohmann::json;

json x; // null
x[0]; // now it's an array: [ null ]

json y; // null
y["foo"]; // now it's an object: { "foo": null }

json z = 42;
z["foo"]; // compiles, throws an exception
```

```
using json = nlohmann::json;

json x; // null
x[0]; // now it's an array: [ null ]

json y; // null
y["foo"]; // now it's an object: { "foo": null }

json z = 42;
z["foo"]; // compiles, throws an exception
```

```cpp
using json = nlohmann::json;

json x; // null
x[0]; // now it's an array: [ null ]

json y; // null
y["foo"]; // now it's an object: { "foo": null }

json z = 42;
z["foo"]; // compiles, throws an exception
```

```
using json = nlohmann::json;

json x; // null
x[0]; // now it's an array: [ null

json y; // null
y["foo"]; // now it's an object: {

json z = 42;
z["foo"]; // compiles, throws an exc
```

```
Value x = Object{
  { "items", Array{ 1, 2, 3 } }
};
```

implies that x is an object

```
Value *item = x.resolve("items", 0);
if (item)
  print(*item); // use *item
```

implies that `x.asObject()["items"]` is an array

`Value` type

```
Value y = Array{
  Object{ { "foo", 1 } }, "two", 3
};

Value *foo = y.resolve(0, "foo");
if (foo)
  print(*foo); // use *foo
```

implies that y is an array

implies that `y.asArray()[0]` is an object

`Value` type

```
Value z = Array{
  Object{
    { "foo", Object{
      { "bar", Array{ 1, 2, 3 } }
    } }
  },
  42
};

auto *v = z.resolve(0, "foo", "bar", 2);
if (v)
  print(*v); // use *v
```

```
Value z = Array{
  Object{
    { "foo", Object{
      { "bar", Array{ 1, 2, 3 } }
    } }
  },
  42
};

auto *v = z.resolve(0);
if (v)
  print(*v); // use *v
```

```
Value z = Array{
  Object{
    { "foo", Object{
      { "bar", Array{ 1, 2, 3 } }
    } }
  },
  42
};

auto *v = z.resolve(1);
if (v)
  print(*v); // use *v
```

```
Value z = Array{
  Object{
    { "foo", Object{
      { "bar", Array{ 1, 2, 3 } }
    } }
  },
  42
};

                                   ???
auto *v = z.resolve(0, "foo", 2);
if (v)
  print(*v); // use *v
```

```
struct Value {
  //...
private:
  const Value *resolveImpl(size_t index) const noexcept {
    auto *array = std::get_if<Array>(&variant());
    if (array && index < array->size())
      return &(*array)[index];
    return nullptr;
  }
  const Value *resolveImpl(const String &key) const noexcept {
    if (auto *object = std::get_if<Object>(&variant())) {
      if (auto i = object->find(key); i != object->end())
        return &i->second;
    }
    return nullptr;
  }
  //...
```

```
struct Value {
  //...
private:
  const Value *resolveImpl(size_t index) const noexcept {
    auto *array = std::get_if<Array>(&variant());
    if (array && index < array->size())
      return &(*array)[index];
    return nullptr;
  }
  const Value *resolveImpl(const String &key) const noexcept {
    if (auto *object = std::get_if<Object>(&variant())) {
      if (auto i = object->find(key); i != object->end())
        return &i->second;
    }
    return nullptr;
  }
  //...
```

```
struct Value {
  //...
  template<typename... T>
  [[nodiscard]] std::enable_if_t<sizeof...(T) >= 1 &&
                  detail::AreTypesConvertibleToStringXorSizeT<T&&...>,
                const Value*> resolve(T&&... refTokens) const noexcept {
    const Value *value = this;
    ((value = value->resolveImpl(std::forward<T>(refTokens))) && ...);
    return value;
  }


  //...
};
```

Value type

```
struct Value {
  //...
  template<typename... T>
    requires (                             sizeof...(T) >= 1 &&
                  detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] const Value*  resolve(T&&... refTokens) const noexcept {
    const Value *value = this;
    ((value = value->resolveImpl(std::forward<T>(refTokens))) && ...);
    return value;
  }


  //...
};
```

`Value` type

```
struct Value {
  //...
  template<typename... T>
    requires (                        sizeof...(T) >= 1 &&
               detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [                                                    ept {
                                                        ...);
  } }
  //...
};
```

```
namespace detail {
  template<typename... T>
  inline constexpr bool AreTypesConvertibleToStringXorSizeT =
    ((std::is_convertible_v<T, std::string> != // exclusive OR
      std::is_convertible_v<T, size_t>) && ...);
}
```

Value type

```cpp
struct Value {
  //...
  template<typename... T>
    requires (                    sizeof...(T) >= 1 &&
              detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] const Value*  resolve(T&&... refTokens) const noexcept {
    const Value *value = this;
    ((value = value->resolveImpl(std::forward<T>(refTokens))) && ...);
    return value;
  }


  //...
};
```

Value type

```
struct Value {
  //...
  template<typename... T>
    requires (                        sizeof...(T) >= 1 &&
              detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] const Value*  resolve(T&&... refTokens) const noexcept {
    const Value *value = this;
    ((value = value->resolveImpl(std::forward<T>(refTokens))) && ...);
    return value;
  }


  //...
};
```

`Value` type

```
struct Value {
  //...
  template<typename... T>
    requires (                          sizeof...(T) >= 1 &&
               detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] const Value*  resolve(T&&... refTokens) const noexcept {
    const Value *value = this;
    (static_cast<bool>(
       value = value->resolveImpl(std::forward<T>(refTokens))
     ) && ...);
    return value;
  }
  //...
};
```

Value type

```
struct Value {
  //...
  template<typename... T>
    requires (                    sizeof...(T) >= 1 &&
              detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] const Value*  resolve(T&&... refTokens) const noexcept {
    const Value *value = this;
    (void)(static_cast<bool>(
       value = value->resolveImpl(std::forward<T>(refTokens))
     ) && ...);
    return value;
  }
  //...
};
```

Value type

```
struct Value {
  //...
  template<typename... T>
    requires (sizeof...(T) >= 1 &&
              detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] Value* resolve(T&&... refTokens) noexcept {
    return const_cast<Value*>(
      std::as_const(*this).resolve(std::forward<T>(refTokens)...)
    );
  }


  //...
};
```

Value type

```
struct Value {
  //...
  template<typename... T>
    requires (sizeof...(T) >= 1 &&
                detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] Value* resolve(T&&... refTokens) noexcept {
    return const_cast<Value*>(
      std::as_const(*this).resolve(std::forward<T>(refTokens)...)
    );
  }


  //...
};
```

`Value` type

```
struct Value {
  //...
  template<typename... T>
    requires (sizeof...(T) >= 1 &&
              detail::AreTypesConvertibleToStringXorSizeT<T&&...>)
  [[nodiscard]] Value* resolve(T&&... refTokens) noexcept {
    return const_cast<Value*>(
      std::as_const(*this).resolve(std::forward<T>(refTokens)...)
    );
  }

  //...
};
```

```
Value x = Object{
  { "items", Array{ 1, 2, 3 } }
};

Value *item = x.resolve("items", 0);
if (item)
  print(*item); // use *item
```

Value type

```cpp
struct Value {
  //...
  using Array = std::vector<Value>;
  using Object = std::unordered_map<String, Value>;
  //...
private:
  //...
  Variant m_data;
};
```

`Value` is incomplete at this point

`Value` type

`std::vector` has to support incomplete types according to the standard

`std::unordered_map` does not *have to* support incomplete types, but de facto supports them in all major implementations of the C++ standard library

except for libstdc++ versions <12

```
struct Value {
  //...
private:
  //...
#if !defined(_GLIBCXX_RELEASE) || _GLIBCXX_RELEASE >= 12
  Variant m_data;
#else
  struct Workaround final {
    //...
  } m_data;
#endif
};
```

`Value` type

```cpp
struct Workaround final {
  //...
private:
  using DummyUnorderedMap = std::unordered_map<String, Array>;
  using DummyVariant = std::variant<Null, Boolean, int64_t,
                                    double, String, Array,
                                    DummyUnorderedMap>;

  alignas(DummyVariant) uint8_t storage[sizeof(DummyVariant)];
} m_data;
```

Value type

```
struct Workaround final {
  //...
private:
  using DummyUnorderedMap = std::unordered_map<String, Array>;
  using DummyVariant = std::variant<Null, Boolean, int64_t,
                                    double, String, Array,
                                    DummyUnorderedMap>;

  alignas(DummyVariant) uint8_t storage[sizeof(DummyVariant)];
} m_data;
```

Value type

```
struct Workaround final {
  //...
private:
  using DummyUnorderedMap = std::unordered_map<String, Array>;
  using DummyVariant = std::variant<Null, Boolean, int64_t,
                                    double, String, Array,
                                    DummyUnorderedMap>;
```

`std::aligned_storage` is deprecated in C++23

```
  alignas(DummyVariant) uint8_t storage[sizeof(DummyVariant)];
} m_data;
```

`Value` type

```
struct Workaround final {
  Workaround() noexcept { ::new(&storage) Variant{}; }
  Workaround(const Workaround &other) {
    ::new(&storage) Variant{ other.operator const Variant&() };
  }
  Workaround(Workaround &&other)
    noexcept(std::is_nothrow_move_constructible_v<Variant>) {
    ::new(&storage) Variant{ std::move(other.operator Variant&()) };
  }
  template<typename... T>
  Workaround(T&&... v)
    noexcept(std::is_nothrow_constructible_v<Variant, T&&...>) {
    ::new(&storage) Variant{ std::forward<T>(v)... };
  }

  //...
} m_data;
```

```
struct Workaround final {
  Workaround() noexcept { ::new(&storage) Variant{}; }
  Workaround(const Workaround &other) {
    ::new(&storage) Variant{ other.operator const Variant&() };
  }
  Workaround(Workaround &&other)
    noexcept(std::is_nothrow_move_constructible_v<Variant>) {
    ::new(&storage) Variant{ std::move(other.operator Variant&()) };
  }
  template<typename... T>
  Workaround(T&&... v)
    noexcept(std::is_nothrow_constructible_v<Variant, T&&...>) {
    ::new(&storage) Variant{ std::forward<T>(v)... };
  }

  //...
} m_data;
```

```
struct Workaround final {
  Workaround() noexcept { ::new(&storage) Variant{}; }
  Workaround(const Workaround &other) {
    ::new(&storage) Variant{ other.operator const Variant&() };
  }
  Workaround(Workaround &&other)
    noexcept(std::is_nothrow_move_constructible_v<Variant>) {
    ::new(&storage) Variant{ std::move(other.operator Variant&()) };
  }
  template<typename... T>
  Workaround(T&&... v)
    noexcept(std::is_nothrow_constructible_v<Variant, T&&...>) {
    ::new(&storage) Variant{ std::forward<T>(v)... };
  }

  //...
} m_data;
```

```cpp
struct Workaround final {
  Workaround() noexcept { ::new(&storage) Variant{}; }
  Workaround(const Workaround &other) {
    ::new(&storage) Variant{ other.operator const Variant&() };
  }
  Workaround(Workaround &&other)
    noexcept(std::is_nothrow_move_constructible_v<Variant>) {
    ::new(&storage) Variant{ std::move(other.operator Variant&()) };
  }
  template<typename... T>
  Workaround(T&&... v)
    noexcept(std::is_nothrow_constructible_v<Variant, T&&...>) {
    ::new(&storage) Variant{ std::forward<T>(v)... };
  }

  //...
} m_data;
```

```
struct Workaround final {
  //...
  ~Workaround() {
    static_assert(sizeof(DummyVariant) == sizeof(Variant));
    static_assert(alignof(DummyVariant) == alignof(Variant));
    operator Variant&().~Variant();
  }
  auto &operator=(const Workaround &other) {
    return operator Variant&() = other.operator const Variant&();
  }
  auto &operator=(Workaround &&other)
    noexcept(std::is_nothrow_move_assignable_v<Variant>) {
    return operator Variant&() = std::move(other.operator Variant&());
  }

  //...
} m_data;
```

```cpp
struct Workaround final {
  //...
  ~Workaround() {
    static_assert(sizeof(DummyVariant) == sizeof(Variant));
    static_assert(alignof(DummyVariant) == alignof(Variant));
    operator Variant&().~Variant();
  }
  auto &operator=(const Workaround &other) {
    return operator Variant&() = other.operator const Variant&();
  }
  auto &operator=(Workaround &&other)
    noexcept(std::is_nothrow_move_assignable_v<Variant>) {
    return operator Variant&() = std::move(other.operator Variant&());
  }

  //...
} m_data;
```

```
struct Workaround final {
  //...
  ~Workaround() {
    static_assert(sizeof(DummyVariant) == sizeof(Variant));
    static_assert(alignof(DummyVariant) == alignof(Variant));
    operator Variant&().~Variant();
  }
  auto &operator=(const Workaround &other) {
    return operator Variant&() = other.operator const Variant&();
  }
  auto &operator=(Workaround &&other)
    noexcept(std::is_nothrow_move_assignable_v<Variant>) {
    return operator Variant&() = std::move(other.operator Variant&());
  }

  //...
} m_data;
```

Which rule?

```
struct Workaround final {
  Workaround() noexcept;
  Workaround(const Workaround &other);
  Workaround(Workaround &&other)
    noexcept(std::is_nothrow_move_constructible_v<Variant>);
  template<typename... T>
  Workaround(T&&... v)
    noexcept(std::is_nothrow_constructible_v<Variant, T&&...>);
  ~Workaround();
  auto &operator=(const Workaround &other);
  auto &operator=(Workaround &&other)
    noexcept(std::is_nothrow_move_assignable_v<Variant>);



  //...
} m_data;
```

Which rule?

Rule of five

```
struct Workaround final {
  Workaround() noexcept;
  Workaround(const Workaround &other);
  Workaround(Workaround &&other)
    noexcept(std::is_nothrow_move_constructible_v<Variant>);
  template<typename... T>
  Workaround(T&&... v)
    noexcept(std::is_nothrow_constructible_v<Variant, T&&...>);
  ~Workaround();
  auto &operator=(const Workaround &other);
  auto &operator=(Workaround &&other)
    noexcept(std::is_nothrow_move_assignable_v<Variant>);



  //...
} m_data;
```

```
struct Workaround final {
  //...
  operator const Variant&() const& noexcept {
    return *std::launder(reinterpret_cast<const Variant*>(&storage));
  }
  operator Variant&() & noexcept {
    return *std::launder(reinterpret_cast<Variant*>(&storage));
  }
  operator Variant&&() && noexcept {
    return std::move(operator Variant&());
  }
  operator const Variant&&() const&& noexcept {
    return std::move(operator const Variant&());
  }

  //...
} m_data;
```

```
struct Value {
  //...
private:
  //...
#if !defined(_GLIBCXX_RELEASE) || _GLIBCXX_RELEASE >= 12
  Variant m_data;
#else
  struct Workaround final {
    //...
  } m_data;
#endif
};
```

Value type

```cpp
Value v;
auto visitor = [](auto&&) {/*...*/};

std::visit(visitor, v); // does not work

std::visit(visitor, v.variant());

visit(visitor, v);
```

visit()

```
Value v;
auto visitor = [](auto&&) {/*...*/};

std::visit(visitor, v); // does not work

std::visit(visitor, v.variant());

visit(visitor, v);
```

visit()

```
Value v;
auto visitor = [](auto&&) {/*...*/};

std::visit(visitor, v); // does not work

std::visit(visitor, v.variant());

visit(visitor, v);
```

visit()

std::visit

Defined in header <variant>

`template< class Visitor, class... Variants >` `constexpr /* see below */ visit( Visitor&& vis, Variants&&... vars );`	(1)	(since C++17)
`template< class R, class Visitor, class... Variants >` `constexpr R visit( Visitor&& vis, Variants&&... vars );`	(2)	(since C++20)
`template< class... Ts >` `auto&& as-variant( std::variant<Ts...>& var );`	(3)	(exposition only*)
`template< class... Ts >` `auto&& as-variant( const std::variant<Ts...>& var );`	(4)	(exposition only*)
`template< class... Ts >` `auto&& as-variant( std::variant<Ts...>&& var );`	(5)	(exposition only*)
`template< class... Ts >` `auto&& as-variant( const std::variant<Ts...>&& var );`	(6)	(exposition only*)

Applies the visitor `vis` (a *Callable* that can be called with any combination of types from variants) to the variants `vars`

Given VariantBases as `decltype(as-variant(std::forward<Variants>(vars))...` (a pack of `sizeof...(Variants)` types):

1) Invokes `vis` as if by

```
INVOKE(std::forward<Visitor>(vis),
       std::get<indices>(std::forward<VariantBases>(vars))...)
```

where `indices` is `as-variant(vars).index()...`.

2) Invokes `vis` as if by

```
INVOKE<R>(std::forward<Visitor>(vis),
          std::get<indices>(std::forward<VariantBases>(vars))..
```

where `indices` is `as-variant(vars).index()...`.

These overloads participate in overload resolution only if every type in VariantBases is a valid type. If the expression denoted by *INVOKE* or *INVOKE<R>* (since C++20) is invalid, or the results of *INVOKE* or *INVOKE<R>* (since C++20) have different types or value categories for different `indices`, the program is ill-formed.

3-6) The exposition-only *as-variant* function templates accept a value whose type can be deduced for `std::variant<Ts...>` (i.e. either `std::variant<Ts...>` or a type derived from `std::variant<Ts...>`), and return the `std::variant` value with the same const-qualification and value category.

3,4) Returns `var`.

5,6) Returns `std::move(var)`.

Argument to `std::visit()` can be either

- `std::variant<T...>`

or

- a type derived from `std::variant<T...>`

C++20


```
template<typename F, typename T>
  requires (std::is_base_of_v<detail::RawBaseValueType<T>,
                              std::remove_cvref_t<T>>)
decltype(auto) visit(F &&f, T &&value) {
  using BaseValueType = detail::RawBaseValueType<T>;
  return std::visit(std::forward<F>(f),
                    std::forward<T>(value).BaseValueType::variant());
}
```

visit()

```
template<typename F, typename T>
  requires (std::is_base_of_v<detail::RawBaseValueType<T>,
                              std::remove_cvref_t<T>>)
decltype(auto) visit(F &&f, T &&value) {
  using BaseValueType = detail::RawBaseValueType<T>;
  return std::visit(std::forward<F>(f),
                    std::forward<T>(value).BaseValueType::variant());
}
```

visit()

```
template<typename F, typename T>
  requires (std::is_base_of_v<detail::RawBaseValueType<T>,
                               std::remove_cvref_t<T>>)
decltype(auto) visit(F &&f, T &&value) {
  using BaseValueType = detail::RawBaseValueType<T>;
  return std::visit(std::forward<F>(f),
                    std::forward<T>(value).BaseValueType::variant());
}
```

visit()

```cpp
template<typename F, typename T>
  requires (std::is_base_of_v<detail::RawBaseValueType<T>,
                              std::remove_cvref_t<T>>)
decltype(auto) visit(F &&f, T &&value) {
  using BaseValueType = detail::RawBaseValueType<T>;
  return std::visit(std::forward<F>(f),
                    std::forward<T>(value).BaseValueType::variant());
}
```

visit()

```
namespace detail {
  void  GetValue(...);             // intentionally not implemented
  Value GetValue(const Value&); // intentionally not implemented

  template<typename T>
  using RawBaseValueType =
    decltype(GetValue(std::declval<std::remove_cvref_t<T>>()));
}
```

visit()

```
namespace detail {
  void  GetValue(...);              // intentionally not implemented
  Value GetValue(const Value&); // intentionally not implemented

  template<typename T>
  using RawBaseValueType =
    decltype(GetValue(std::declval<std::remove_cvref_t<T>>()));
}
```

visit()

```
auto foo() {
  return expr;
}

const auto &bar() {
  return expr;
}

decltype(expr) baz() {
  return expr;
}
```

decltype(auto)

```
auto foo() {
  return expr;
}
```

returns T as deduced in a call

`test(expr)`

to function template

```
template<typename T>
void test(T);
```

```
const auto &bar() {
  return expr;
}

decltype(expr) baz() {
  return expr;
}
```

decltype(auto)

```
T foo() {
  return expr;
}
```

returns T as deduced in a call

```
test(expr)
```

to function template

```
template<typename T>
void test(T);
```

```
const auto &bar() {
  return expr;
}

decltype(expr) baz() {
  return expr;
}
```

decltype(auto)

```
auto foo() {
  return expr;
}

const auto &bar() {
  return expr;
}

decltype(expr) baz() {
  return expr;
}
```

returns T as deduced in a call

```
test(expr)
```

to function template

```
template<typename T>
void test(const T&);
```

decltype(auto)

```
auto foo() {
  return expr;
}

const  T  &bar() {
  return expr;
}

decltype(expr) baz() {
  return expr;
}
```

returns T as deduced in a call

```
test(expr)
```

to function template

```
template<typename T>
void test(const T&);
```

decltype(auto)

```
auto foo() {
  return expr;
}

const auto &bar() {
  return expr;
}

decltype(expr) baz() {
  return expr;
}
```

decltype(auto)

```
auto foo() {
  return expr;
}

const auto &bar() {
  return expr;
}

decltype(auto) baz() {
  return expr;
}
```

decltype(auto)

```
template<typename F, typename T>
  requires (std::is_base_of_v<detail::RawBaseValueType<T>,
                                    std::remove_cvref_t<T>>)
decltype(auto) visit(F &&f, T &&value) {
  using BaseValueType = detail::RawBaseValueType<T>;
  return std::visit(std::forward<F>(f),
                    std::forward<T>(value).BaseValueType::variant());
}
```

visit()

```
struct Value {
  using Null = std::monostate;
  using Boolean = bool;
  using String = std::string;
  using Array = std::vector<Value>;
  using Object = std::unordered_map<String, Value>;
  using Variant =
    std::variant<Null, Boolean, int64_t, double, String, Array, Object>;
  //...
};
```

Allocator support

```cpp
template<typename Allocator>
struct BasicValue {
  using Null = std::monostate;
  using Boolean = bool;
  using String = std::basic_string<char, std::char_traits<char>,
    detail::ReboundAllocator<Allocator, char>>;
  using Array = std::vector<BasicValue,
    detail::ReboundAllocator<Allocator, BasicValue>>;
  using Object = std::unordered_map<String, BasicValue,
    std::hash<String>, std::equal_to<String>,
    detail::ReboundAllocator<Allocator,
                                          std::pair<const String, BasicValue>>>;
  using Variant =
    std::variant<Null, Boolean, int64_t, double, String, Array, Object>;
  //...
};
```

```
namespace detail {
  template<typename Allocator, typename T>
  using ReboundAllocator =
    typename std::allocator_traits<Allocator>::template rebind_alloc<T>;
}
```

```
  using String = std::basic_string<char, std::char_traits<char>,
    detail::ReboundAllocator<Allocator, char>>;
  using Array = std::vector<BasicValue,
    detail::ReboundAllocator<Allocator, BasicValue>>;
  using Object = std::unordered_map<String, BasicValue,
    std::hash<String>, std::equal_to<String>,
    detail::ReboundAllocator<Allocator,
                                 std::pair<const String, BasicValue>>>;
  using Variant =
    std::variant<Null, Boolean, int64_t, double, String, Array, Object>;
  //...
};
```

```cpp
template<typename Allocator>
struct BasicValue {
  using Null = std::monostate;
  using Boolean = bool;
  using String = std::basic_string<char, std::char_traits<char>,
    detail::ReboundAllocator<Allocator, char>>;
  using Array = std::vector<BasicValue,
    detail::ReboundAllocator<Allocator, BasicValue>>;
  using Object = std::unordered_map<String, BasicValue,
    std::hash<String>, std::equal_to<String>,
    detail::ReboundAllocator<Allocator,
                                             std::pair<const String, BasicValue>>>;
  using Variant =
    std::variant<Null, Boolean, int64_t, double, String, Array, Object>;
  //...
};
```

```
template<typename Allocator>
struct BasicValue {
  using Null = std::monostate;
  using Boolean = bool;
  using String = std::basic_string<char, std::char_traits<char>,
    detail::ReboundAllocator<Allocator, char>>;
  using Array = std::vector<BasicValue,
    detail::ReboundAllocator<Allocator, BasicValue>>;
  using Object = std::unordered_map<String, BasicValue,
    std::hash<String>, std::equal_to<String>,
    detail::ReboundAllocator<Allocator,
                                        std::pair<const String, BasicValue>>>;
  using Variant =
    std::variant<Null, Boolean, int64_t, double, String, Array, Object>;
  //...
};
```

```
template<typename Allocator>
struct BasicValue {
  //...
  BasicValue(const Allocator&) noexcept {}
  BasicValue(const BasicValue &other, const Allocator &a) :
    m_data{ construct(other.variant(), a) } {}
  BasicValue(BasicValue &&other, const Allocator &a) :
    m_data{ construct(std::move(other.variant()), a) } {}
  //...
};
```

uses-allocator machinery support

Allocator support

```
template<typename V>
Variant construct(V &&other, const Allocator &a) {
  if (other.valueless_by_exception())
    return std::forward<V>(other);
  return std::visit([&a](auto &&val) {
    using U = decltype(val);
    using T = detail::RemoveCVRef<U>;
    if constexpr (std::is_same_v<T, Object> ||
                  std::is_same_v<T, Array> ||
                  std::is_same_v<T, String>) {
      return Variant{ std::in_place_type<T>, std::forward<U>(val), a };
    }
    else {
      return Variant{ std::in_place_type<T>, val };
    }
  }, std::forward<V>(other));
}
```

```cpp
template<typename V>
Variant construct(V &&other, const Allocator &a) {
  if (other.valueless_by_exception())
    return std::forward<V>(other);
  return std::visit([&a](auto &&val) {
    using U = decltype(val);
    using T = detail::RemoveCVRef<U>;
    if constexpr (std::is_same_v<T, Object> ||
                  std::is_same_v<T, Array> ||
                  std::is_same_v<T, String>) {
      return Variant{ std::in_place_type<T>, std::forward<U>(val), a };
    }
    else {
      return Variant{ std::in_place_type<T>, val };
    }
  }, std::forward<V>(other));
}
```

```
template<typename V>
Variant construct(V &&other, const Allocator &a) {
  if (other.valueless_by_exception())
    return std::forward<V>(other);
  return std::visit([&a](auto &&val) {
    using U = decltype(val);
    using T = detail::RemoveCVRef<U>;
    if constexpr (std::is_same_v<T, Object> ||
                  std::is_same_v<T, Array> ||
                  std::is_same_v<T, String>) {
      return Variant{ std::in_place_type<T>, std::forward<U>(val), a };
    }
    else {
      return Variant{ std::in_place_type<T>, val };
    }
  }, std::forward<V>(other));
}
```

```
template<typename V>
Variant construct(V &&other, const Allocator &a) {
  if (other.valueless_by_exception())
    return std::forward<V>(other);
  return std::visit([&a](auto &&val) {
    using U = decltype(val);
    using T = detail::RemoveCVRef<U>;
    if constexpr (std::is_same_v<T, Object> ||
                  std::is_same_v<T, Array> ||
                  std::is_same_v<T, String>) {
      return Variant{ std::in_place_type<T>, std::forward<U>(val), a };
    }
    else {
      return Variant{ std::in_place_type<T>, val };
    }
  }, std::forward<V>(other));
}
```

passing allocator a

```
template<typename V>
Variant construct(V &&other, const Allocator &a) {
  if (other.valueless_by_exception())
    return std::forward<V>(other);
  return std::visit([&a](auto &&val) {
    using U = decltype(val);
    using T = detail::RemoveCVRef<U>;
    if constexpr (std::is_same_v<T, Object> ||
                  std::is_same_v<T, Array> ||
                  std::is_same_v<T, String>) {
      return Variant{ std::in_place_type<T>, std::forward<U>(val), a };
    }
    else {
      return Variant{ std::in_place_type<T>, val };
    }
  }, std::forward<V>(other));
}
```

```
template<typename Allocator>
struct BasicValue {
  //...
};

using Value = BasicValue<std::allocator<char>>;

namespace std {
  template<typename A1, typename A2> // uses-allocator machinery support
  struct uses_allocator<BasicValue<A1>, A2> : true_type {};
}
```

Allocator support

```cpp
struct Workaround final {
  //...
private:
  using DummyUnorderedMap = std::unordered_map<String, Array,
        std::hash<String>, std::equal_to<String>,
        detail::ReboundAllocator<Allocator,
                                 std::pair<const String, Array>>>;
  using DummyVariant = std::variant<Null, Boolean, int64_t,
                                    double, String, Array,
                                    DummyUnorderedMap>;

  alignas(DummyVariant) uint8_t storage[sizeof(DummyVariant)];
} m_data;
```

Allocator support

```cpp
namespace detail {
  void GetValue(...);               // intentionally not implemented
  template<typename Allocator>
  BasicValue<Allocator> GetValue(const BasicValue<Allocator>&);

  template<typename T>
  using RawBaseValueType =
    decltype(GetValue(std::declval<std::remove_cvref_t<T>>()));
}
```

Allocator support

```
using PmrValue =
  BasicValue<std::pmr::polymorphic_allocator<char>>;

PmrValue a = "hello"; // uses std::pmr::get_default_resource()
```

Allocator support

Most Malleable Memory Management Method in C++ by Björn Fahller

https://youtu.be/ptMFLSAkRj0

```
struct Foo {
  Value v;
  std::vector<int> bar;
};

const Array a;
Value c;
c = a;
```

Clang (any version) + libstdc++ version <12:

```
error: call to implicitly-deleted copy constructor of
'std::pair<const std::basic_string<char>, BasicValue<std::allocator<char>>>'
```

Allocator support

```
struct Foo {
  Value v;
  std::vector<int> bar;
};

const Array a;
Value c;
c = a;
```

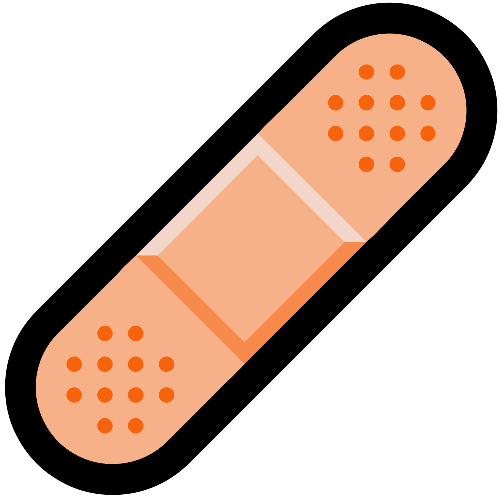
https://github.com/llvm/llvm-project/issues/84487
[clang] fails to compile valid code involving `variant` and `unordered_map` with libstdc++ version <12

Clang (any version) + libstdc++ version <12:

```
error: call to implicitly-deleted copy constructor of
'std::pair<const std::basic_string<char>, BasicValue<std::allocator<char>>>'
```

Allocator support

```
#if defined(_GLIBCXX_RELEASE) && _GLIBCXX_RELEASE < 12 && \
    defined(__clang__)
// clang needs this for some reason
static_assert(std::is_copy_constructible_v<Value>);
#endif
```



Allocator support

What we've covered

- implemented a variant-like value type for working with JSON values
  - rule of zero
  - worked around bogus variant construction/assignment in MS implementation (fixed within P0608, and in the latest VS release)
  - implemented rich interface that's easy to use correctly and hard to use incorrectly
  - worked around inability to use incomplete types (`std::unordered_map` in libstdc++ versions <12)
    - rule of five
- added allocator support, uses-allocator functionality support
  - worked around Clang compilation bug with libstdc++ versions <12


ONE DOES NOT SIMPLY
WRITE A JSON LIBRARY IN C++

minjsoncpp

Minimalistic JSON C++ library

https://github.com/toughengineer/minjsoncpp

JSON in C++:
designing a type for working with JSON values

Pavel Novikov

X @cpp_ape

Thanks to Stephan T. Lavavej for clarifications on MS implementation.

Slides: bit.ly/4ifnxsv

References

- RFC 8259: The JavaScript Object Notation (JSON) Data Interchange Format https://datatracker.ietf.org/doc/html/rfc8259
- “A sane variant converting constructor” by Zhihao Yuan https://wg21.link/p0608
- Macro _MSVC_STL_UPDATE https://github.com/microsoft/STL/wiki/Macro-_MSVC_STL_UPDATE
- Deprecate std::aligned_storage and std::aligned_union by CJ Johnson https://wg21.link/p1413
- Most Malleable Memory Management Method in C++ by Björn Fahller https://www.youtube.com/watch?v=ptMFLSAkRj0
- [clang] fails to compile valid code involving `variant` and `unordered_map` with libstdc++ version <12 https://github.com/llvm/llvm-project/issues/84487
- minjsoncpp — Minimalistic JSON C++ library https://github.com/toughengineer/minjsoncpp