Serialization in C++ has never been easier! But wait, there's more...

Pavel Novikov

@cpp_ape

Align Technology R&D

We’ll talk about

- Reflection
- Metaprogramming

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- It’s not in C++ 20

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  - mere mortals will be able to use it in 2027 … probably…

METAPROGRAMMING

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- Reflection
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- It's not in C++ 20
  - *maybe* will be in C++ 23
  - probably will be in C++ 26
  - mere mortals will be able to use it in 2027 … probably…
  - *everything* can change entirely…

METAPROGRAMMING

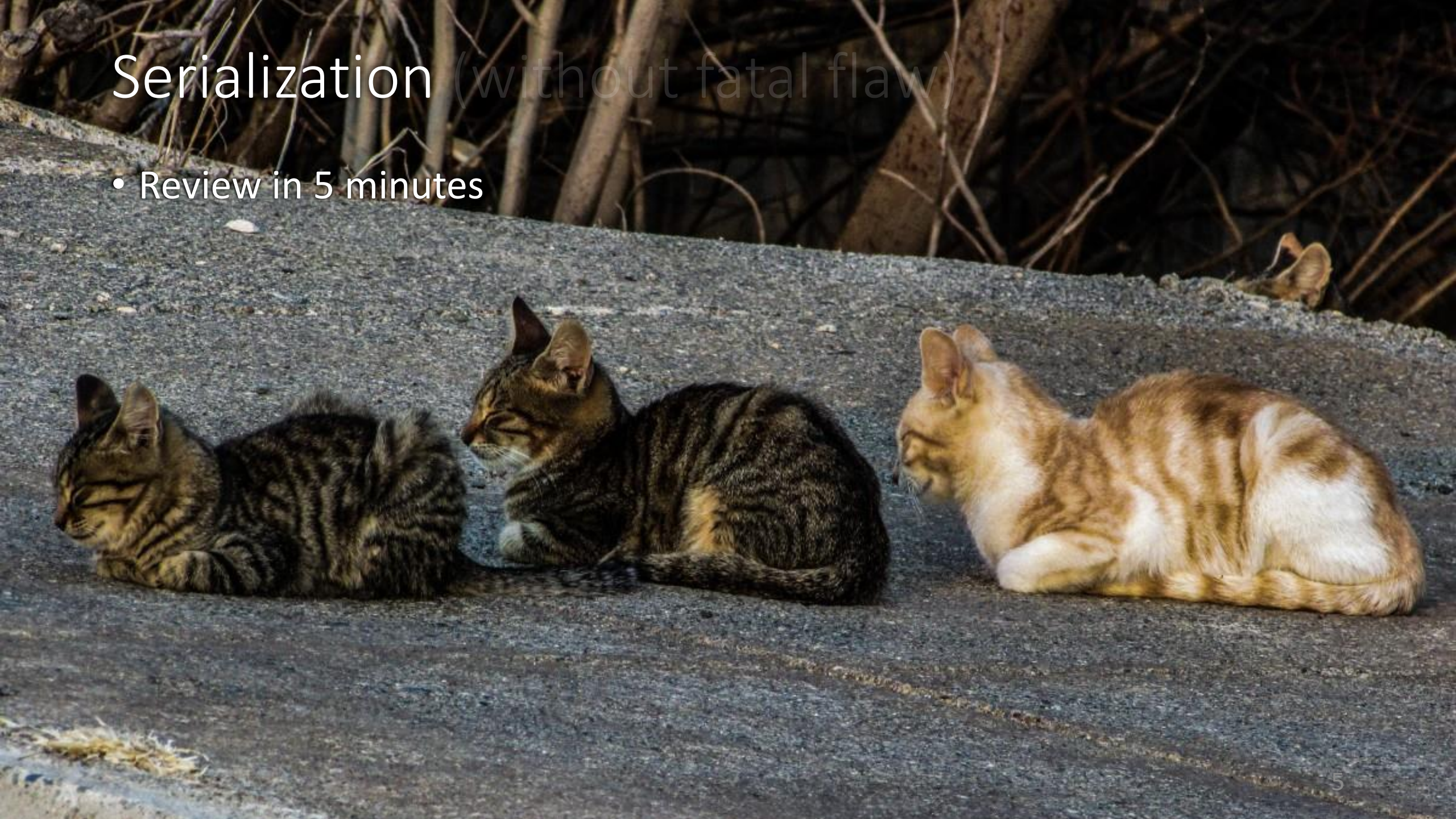
It’s

```
namespace meta = std::experimental::meta;

template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  using Type = std::decay_t<T>;
  consteval {
    for (auto m : meta::data_member_range(reflexpr(Type)))
      -> fragment {
        requires Visitor &&visit;
        requires T &&value;
        visit(value.idexpr(%{ m }), meta::name_of(%{ m }));
      };
  }
}
```

Serialization (without fatal flaw)

- Review in 5 minutes



Serialization (without fatal flaw)

```
struct Foo {
  std::optional<int> empty;
  int number = 42;
  std::string string = "bleh!";
  std::vector<int> array = {
    1,
    2,
    3
  };
  struct {
    std::string iAm = "nested!";
  } nestedStruct;
  struct {} emptyStruct;
};
```

```
{
  "empty": null,
  "number": 42,
  "string": "bleh!",
  "array": [
    1,
    2,
    3
  ],
  "nestedStruct": {
    "iAm": "nested!"
  },
  "emptyStruct": {}
}
```

Serialization

```
serialize(std::cout, Foo{});
```

```
struct Foo {
  std::optional<int> empty;
  int number = 42;
  std::string string = "bleh!";
  std::vector<int> array = {
    1,
    2,
    3
  };
  struct {
    std::string iAm = "nested!";
  } nestedStruct;
  struct {} emptyStruct;
};
```

```
{
  "empty": null,
  "number": 42,
  "string": "bleh!",
  "array": [
    1,
    2,
    3
  ],
  "nestedStruct": {
    "iAm": "nested!"
  },
  "emptyStruct": {}
}
```

Serialization (without fatal flaw)

```
struct SerializationHelper {
  //...
  template<typename T>
  void printValue(const std::vector<T> &vector, size_t indent);
  template<typename T>
  void printValue(const std::optional<T> &value, size_t indent);
  template<typename T>
  void printValue(const T &value, size_t indent);
  template<typename T>
  static void iterateMembersHelper(std::ostream &stream, const T &value, size_t indent);
};

template<typename T>
void serialize(std::ostream &stream, const T &value) {
  SerializationHelper{ stream }.printValue(value, /*indent*/ 0);
}
```

Serialization (without fatal flaw)

```
struct SerializationHelper {
  //...
  template<typename T>
  void printValue(const std::vector<T> &vector, size_t indent);
  template<typename T>
  void printValue(const std::optional<T> &value, size_t indent);
  template<typename T>
  void printValue(const T &value, size_t indent);
  template<typename T>
  static void iterateMembersHelper(std::ostream &stream, const T &value, size_t indent);
};

template<typename T>
void serialize(std::ostream &stream, const T &value) {
  SerializationHelper{ stream }.printValue(value, /*indent*/ 0);
}
```

Serialization (without fatal flaw)

```
struct SerializationHelper {
  //...
  template<typename T>
  void printValue(const std::vector<T> &vector, size_t indent);
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  void printValue(const std::optional<T> &value, size_t indent);
  template<typename T>
  void printValue(const T &value, size_t indent);
  template<typename T>
  static void iterateMembersHelper(std::ostream &stream, const T &value, size_t indent);
};

template<typename T>
void serialize(std::ostream &stream, const T &value) {
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Serialization (without fatal flaw)

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  //...
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  void printValue(const std::optional<T> &value, size_t indent);
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  void printValue(const T &value, size_t indent);
  template<typename T>
  static void iterateMembersHelper(std::ostream &stream, const T &value, size_t indent);
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```

Serialization (without fatal flaw)

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  //...
  template<typename T>
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  void printValue(const std::optional<T> &value, size_t indent);
  template<typename T>
  void printValue(const T &value, size_t indent);
  template<typename T>
  static void iterateMembersHelper(std::ostream &stream, const T &value, size_t indent);
};

template<typename T>
void serialize(std::ostream &stream, const T &value) {
  SerializationHelper{ stream }.printValue(value, /*indent*/ 0);
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```

Serialization (without fatal flaw)

```
struct SerializationHelper {
  //...
  template<typename T>
  void printValue(const std::vector<T> &vector, size_t indent);
  template<typename T>
  void printValue(const std::optional<T> &value, size_t indent);
  template<typename T>
  void printValue(const T &value, size_t indent);
  template<typename T>
  static void iterateMembersHelper(std::ostream &stream, const T &value, size_t indent);
};

template<typename T>
void serialize(std::ostream &stream, const T &value) {
  SerializationHelper{ stream }.printValue(value, /*indent*/ 0);
}
```

Serialization (without fatal flaw)

```cpp
int number = 42;
serialize(std::cout, number);


std::string string = "#cpponsea";
serialize(std::cout, string);


std::vector<std::string> array = {
  "one",
  "two",
  "three"
};
serialize(std::cout, array);
```

```
42


"#cpponsea"


[
  "one",
  "two",
  "three"
]
```

Serialization (without fatal flaw)

```
template<typename T>
void printValue(const T &value, size_t indent) {
  if constexpr (std::is_same_v<T, bool>) {
    stream << (value ? "true" : "false");
  }
  else if constexpr (std::is_same_v<T, int>) {
    stream << value;
  }
  else if constexpr (std::is_same_v<T, std::string>) {
    stream << std::quoted(value);
  }
  else {
    iterateMembersHelper(stream, value, indent);
  }
}
```

Serialization (without fatal flaw)

```
template<typename T>
void printValue(const T &value, size_t indent) {
  if constexpr (std::is_same_v<T, bool>) {
    stream << (value ? "true" : "false");
  }
  else if constexpr (std::is_same_v<T, int>) {
    stream << value;
  }
  else if constexpr (std::is_same_v<T, std::string>) {
    stream << std::quoted(value);
  }
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    iterateMembersHelper(stream, value, indent);
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}
```

Serialization (without fatal flaw)

```
template<typename T>
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    stream << (value ? "true" : "false");
  }
  else if constexpr (std::is_same_v<T, int>) {
    stream << value;
  }
  else if constexpr (std::is_same_v<T, std::string>) {
    stream << std::quoted(value);
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Serialization (without fatal flaw)

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    stream << (value ? "true" : "false");
  }
  else if constexpr (std::is_same_v<T, int>) {
    stream << value;
  }
  else if constexpr (std::is_same_v<T, std::string>) {
    stream << std::quoted(value);
  }
  else {
    iterateMembersHelper(stream, value, indent);
  }
}
```

Serialization (without fatal flaw)

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void printValue(const T &value, size_t indent) {
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    stream << (value ? "true" : "false");
  }
  else if constexpr (std::is_same_v<T, int>) {
    stream << value;
  }
  else if constexpr (std::is_same_v<T, std::string>) {
    stream << std::quoted(value);
  }
  else {
    iterateMembersHelper(stream, value, indent);
  }
}
```

Serialization (without fatal flaw)

```
struct Bar {
  int number = 42;
  std::string string = "boring string";
  std::vector<int> array = { 1, 2, 3 };
};

serialize(std::cout, Bar{});
```

Serialization (without fatal flaw)

```
struct Bar {
  int number = 42;
  std::string string = "boring string";
  std::vector<int> array = { 1, 2, 3 };
};

serialize(std::cout, Bar{});
```

```
error : use of undeclared identifier 'iterateMembers'
```

Serialization (without fatal flaw)

```
template<typename T>
static void iterateMembersHelper(std::ostream &stream,
                                 const T &value,
                                 size_t indent) {
  static_assert(std::is_class_v<T>);
  stream << '{';
  SerializationHelper helper{ stream };
  auto visit = [&helper, indent = indent + Indent](const auto& value,
                                                   std::string_view name) {
    helper.print(value, name, indent);
  };
  iterateMembers(visit, value);
  if (!helper.empty)
    helper.printNewLineAndIndent(indent);
  stream << '}';
}
```

Serialization (without fatal flaw)

```
template<typename T>
static void iterateMembersHelper(std::ostream &stream,
                                 const T &value,
                                 size_t indent) {
  static_assert(std::is_class_v<T>);
  stream << '{';
  SerializationHelper helper{ stream };
  auto visit = [&helper, indent = indent + Indent](const auto& value,
                                                   std::string_view name) {
    helper.print(value, name, indent);
  };
  iterateMembers(visit, value);
  if (!helper.empty)
    helper.printNewLineAndIndent(indent);
  stream << '}';
}
```

Serialization (without fatal flaw)

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template<typename T>
static void iterateMembersHelper(std::ostream &stream,
                                 const T &value,
                                 size_t indent) {
  static_assert(std::is_class_v<T>);
  stream << '{';
  SerializationHelper helper{ stream };
  auto visit = [&helper, indent = indent + Indent](const auto& value,
                                                   std::string_view name) {
    helper.print(value, name, indent);
  };
  iterateMembers(visit, value);
  if (!helper.empty)
    helper.printNewLineAndIndent(indent);
  stream << '}';
}
```

```
template<typename T>
void print(const T &value,
           std::string_view name,
           size_t indent) {
  //...
  stream << std::quoted(name) << ':';
  printValue(value, indent);
}
```

Serialization (without fatal flaw)

```
struct Bar {
  int number = 42;
  std::string string = "boring string";
  std::vector<int> array = { 1, 2, 3 };
};
template<typename Visitor>
void iterateMembers(Visitor &&visit, const Bar &bar) {
  visit(bar.number, "number");
  visit(bar.string, "string");
  visit(bar.array, "array");
}

serialize(std::cout, Bar{});
```

Serialization (without fatal flaw)

```
struct Bar {
  int number = 42;
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  std::vector<int> array = { 1, 2, 3 };
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template<typename Visitor>
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Serialization (without fatal flaw)

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  int number = 42;
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template<typename Visitor>
void iterateMembers(Visitor &&visit, const Bar &bar) {
  visit(bar.number, "number");
  visit(bar.string, "string");
  visit(bar.array, "array");
}

serialize(std::cout, Bar{});
```

```
{
  "number": 42,
  "string": "boring string",
  "array": [
    1,
    2,
    3
  ]
}
```

Reflection

`reflexpr` and `meta::info`

```
int value = 42;
constexpr meta::info info = reflexpr(value);

if (meta::is_named(info))
  std::cout << meta::name_of(info);
```

outputs:

```
value
```

reflexpr and meta::info

```
constexpr meta::info info = reflexpr(int);

if (meta::is_named(info))
  std::cout << meta::name_of(info);
```

outputs:

```
int
```

reflexpr and meta::info

```
template<typename T>
void printValue(const T &value, size_t indent) {

  if constexpr (std::is_same_v<T, bool>) {
    stream << (value ? "true" : "false");
  }
  else if constexpr (std::is_same_v<T, int>) {
    stream << value;
  }
  else if constexpr (std::is_same_v<T, std::string>) {
    stream << std::quoted(value);
  }
  else {
    iterateMembersHelper(stream, value, indent);
  }
}
```

reflexpr and meta::info

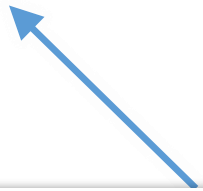
```
template<typename T>
void printValue(const T &value, size_t indent) {
  constexpr auto type = reflexpr(T);
  if constexpr (type == reflexpr(bool)) {
    stream << (value ? "true" : "false");
  }
  else if constexpr (type == reflexpr(int)) {
    stream << value;
  }
  else if constexpr (type == reflexpr(std::string)) {
    stream << std::quoted(value);
  }
  else {
    iterateMembersHelper(stream, value, indent);
  }
}
```

reflexpr and meta::info

```
consteval size_t dataMemberCount(meta::info info) {
  size_t count = 0;
  for (auto m : meta::data_member_range(info))
    ++count;
  return count;
}
```

reflexpr and meta::info

```
consteval size_t dataMemberCount(meta::info info) {
  size_t count = 0;
  for (auto m : meta::data_member_range(info))
    ++count;
  return count;
}
```



meta::data_members_of is not yet implemented

reflexpr and meta::info

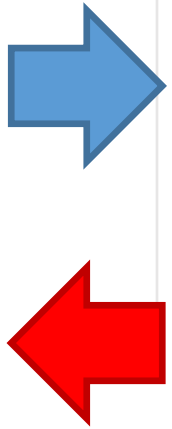
```
struct Widget {
  int foo;
  std::string bar;
  std::vector<int> baz;
};

constexpr auto info = reflexpr(Widget);
std::cout << meta::name_of(info) << " has "
          << dataMemberCount(info) << " data members";
```

outputs:

```
Widget has 3 data members
```

Reifiers

code	metainformation
`int value = 42;`	`constexpr auto info = reflexpr(value);`
`value`	`idexpr(info)`



idexpr

```
int value = 42;
constexpr auto info = reflexpr(value);

std::cout << idexpr(info);
```

outputs:

```
42
```

idexpr

```
int value = 42;
constexpr auto info = reflexpr(value);

std::cout << idexpr(info);
```

outputs:

```
42
```

unqualid

```
int value = 42;

std::cout << unqualid("value");
```

outputs:

```
42
```

unqualid

```
int value = 42;

std::cout << unqualid("value");
```

outputs:

```
42
```

unqualid

```
Widget w;
w.bar = "text";

std::cout << w.unqualid("bar");
```

outputs:

```
text
```

unqualid

```
Widget w;
w.bar = "text";

std::cout << w.unqualbar("bar");
```

outputs:

```
text
```

Reifiers

typename

```
constexpr auto info = reflexpr(int);
typename(info) value = 42;
```

valueof

```
const int Const = 23;
std::cout << valueof(reflexpr(Const));
```

templarg

```
template<typename T> void foo();
foo<templarg(reflexpr(Const))>();

template<int V> void bar();
bar<templarg(reflexpr(Const))>();
```

Reifiers

typename

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constexpr auto info = reflexpr(int);
typename(info) value = 42;
```

valueof

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

Reifiers

typename

```
constexpr auto info = reflexpr(int);
typename(info) value = 42;
```

valueof

```
const int Const = 23;
std::cout << valueof(reflexpr(Const));
```

templarg

```
template<typename T> void foo();
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bar<templarg(reflexpr(Const))>();
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Reifiers

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constexpr auto info = reflexpr(int);
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valueof

```
const int Const = 23;
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templarg

```
template<typename T> void foo();
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template<int V> void bar();
bar<templarg(reflexpr(Const))>();
```

Reflection

```
template<typename Enum>
std::string_view toString(Enum value) {
  constexpr auto info = reflexpr(Enum);
  for constexpr (auto m : meta::members_of(info))
    if (value == valueof(m))
      return meta::name_of(m);
  return {};
}
```

Reflection

```
template<typename Enum>
std::string_view toString(Enum value) {
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}
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Reflection

```
template<typename Enum>
std::string_view toString(Enum value) {
  constexpr auto info = reflexpr(Enum);
  template for(constexpr auto m : meta::members_of(info))
    if (value == valueof(m))
      return meta::name_of(m);
  return {};
}
```

does not currently work

Reflection

```
template<typename Enum>
consteval size_t getEnumMemberCount() {
  auto info = reflexpr(Enum);
  size_t count = 0;
  for (auto m : meta::members_of(info))
    ++count;
  return count;
}
```

Reflection

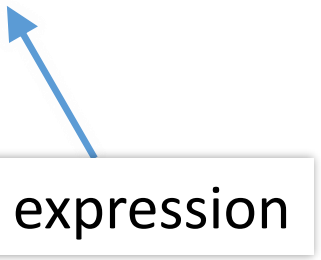
```
template<typename Enum>
consteval auto getEnumMemberName(size_t index) {
  auto info = reflexpr(Enum);
  auto it = meta::members_of(info).begin();
  for (; index; --index)
    ++it;
  return meta::name_of(*it);
}
```

Reflection

```
template<typename Enum, size_t... I>
std::string_view toStringImpl(Enum value,
                              std::index_sequence<I...>){
  std::string_view name;
  (void)((
    value == Enum::unqualid(getEnumMemberName<Enum>(I)) ?
      (name = getEnumMemberName<Enum>(I), true) :
      false
    ) || ...
  );
  return name;
}
```

Reflection

```
template<typename Enum, size_t... I>
std::string_view toStringImpl(Enum value,
                              std::index_sequence<I...>){
  std::string_view name;
  (void)((
    value == Enum::unqualid(getEnumMemberName<Enum>(I)) ?
      (name = getEnumMemberName<Enum>(I), true) :
      false
    ) || ...
  );
  return name;
}
```



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Reflection

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  (void)((
    value == Enum::unqualid(getEnumMemberName<Enum>(I)) ?
      (name = getEnumMemberName<Enum>(I), true) :
      false
    ) || ...
  );
  return name;
}
```

Reflection

```
template<typename Enum>
concept Enumeration = std::is_enum_v<Enum>;

template<Enumeration Enum>
std::string_view toString(Enum value) {
  using IndexSequence =
    std::make_index_sequence<getEnumMemberCount<Enum>()>;
  return toStringImpl(value, IndexSequence{});
}
```

Reflection

```
enum class Enum { One, Two, Three };

std::cout << toString(Enum::One) << '\n';
std::cout << toString(Enum::Two) << '\n';
std::cout << toString(Enum::Three) << '\n';
```

outputs:

```
One
Two
Three
```

Reflection

```
enum class Enum { One, Two, Three };

std::cout << toString(Enum::One) << '\n';
std::cout << toString(Enum::Two) << '\n';
std::cout << toString(Enum::Three) << '\n';
```

outputs:

```
One
Two
Three
```


I CAN HAS
SERIALIZATION?

Serialization only using reflexction

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  constexpr auto type = reflexpr(std::decay_t<T>);
  template for (constexpr auto m :
                  meta::data_member_range(type))
    visit(value.idexpr(m), meta::name_of(m));
}
```

Serialization only using reflexction

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  constexpr auto type = reflexpr(std::decay_t<T>);
  template for (constexpr auto m :
                  meta::data_member_range(type))
    visit(value.idexpr(m), meta::name_of(m));
}
```

does not currently work

Serialization only using reflexction

```
consteval size_t dataMemberCount(meta::info info) {
  size_t count = 0;
  for (auto m : meta::data_member_range(info))
    ++count;
  return count;
}
```

Serialization only using reflexction

```
template<typename T>
consteval auto getMemberName(size_t index) {
  auto it = meta::data_member_range(reflexpr(T)).begin();
  for (; index; --index)
    ++it;
  return meta::name_of(*it);
}
```

Serialization only using reflexction

```
template<typename Visitor, typename T, size_t... I>
void iterateMembersImpl(Visitor &&visit,
                        T && object,
                        std::index_sequence<I...>) {
  using Type = std::decay_t<T>;
  (
    visit(object.unqualid(getMemberName<Type>(I)),
          getMemberName<Type>(I))
    , ...
  );
}
```

Serialization only using reflexction

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&object) {
  using Type = std::decay_t<T>;
  using IndexSequence =
    std::make_index_sequence<
      dataMemberCount(reflexpr(Type))>;
  iterateMembersImpl(std::forward<Visitor>(visit),
                     std::forward<T>(object),
                     IndexSequence{});
}
```

Serialization only using reflexction

```cpp
struct Bar {
  int number = 42;
  std::string string = "boring string";
  std::vector<int> array = { 1, 2, 3 };
};

serialize(std::cout, Bar{});
```

```json
{
  "number": 42,
  "string": "boring string",
  "array": [
    1,
    2,
    3
  ]
}
```


Metaprogramming
[adult swim]

Metaprogramming

- injection
- fragments
- metaprograms

Injection

```
consteval -> ...
```

Injection

```
namespace a {
  int value = 42;
}

namespace b {
  consteval -> reflexpr(a::value);
}
```

Injection

```
namespace a {
   int value = 42;
}

namespace b {
   consteval int value_of(expr a::value);
}
```

Fragments

```
constexpr auto frag = fragment {};
```

Fragments

```
constexpr auto frag = fragment {};

consteval -> frag;
```

Fragments

```
constexpr auto frag = fragment {};

consteval -> frag;


consteval -> fragment {};
```

Fragments

```
consteval -> fragment {
  std::string value = "injected variable";
};
```

Fragments

```
consteval -> fragment {
  std::string value = "injected variable";
};
```

Metaprograms

```
consteval {
  -> fragment {
    std::string value = "injected variable";
  };
}
```

Metaprograms

```
void foo() {
  consteval {
    -> fragment {
      std::string value = "injected variable";
    };
  }
  use(value);
}
```

Metaprograms

```
consteval void immediateFunction() {
  -> fragment {
    std::string value = "injected variable";
  };
}

void foo() {
  consteval { immediateFunction(); }
  use(value);
}
```

Unquote operator

```
template<typename T>
consteval void injectName() {
  auto info = reflexpr(T);
  -> fragment {
    const std::string name = meta::name_of(info);
  };
}
```

Unquote operator

```
template<typename T>
consteval void injectName() {
  auto info = reflexpr(T);
  -> fragment {
    const std::string name = meta::name_of(info);
  };
}
```

reference to local variable

Unquote operator

```
template<typename T>
consteval void injectName() {
  auto info = reflexpr(T);
  -> fragment {
    const std::string name = meta::name_of(%{ info });
  };
}
```

Unquote operator

```
template<typename T>
consteval void injectName() {
  auto info = reflexpr(T);
  -> fragment {
    const std::string name = meta::name_of(%{ info });
  };
}
```

Unquote operator

```
template<typename T>
consteval void injectName() {
  auto info = reflexpr(T);
  -> fragment {
    const std::string name = meta::name_of(%{ info });
  };
}
```

Unquote operator

```
template<typename T>
consteval void injectName() {
  auto info = reflexpr(T);
  -> fragment {
    const std::string name = meta::name_of(%{ info });
  };
}
```

Fragment requirements

```
constexpr auto initialValueFrag = fragment {
  requires typename T;

  T initialValue{};
};
```

Fragment requirements

```
constexpr auto initialValueFrag = fragment {
  requires typename T;

  T initialValue{};
};

struct T { int i = 0; };
```

Fragment requirements

```
constexpr auto initialValueFrag = fragment {
  requires typename T;

  T initialValue{};
};

struct T { int i = 0; };

consteval -> initialValueFrag;
std::cout << "initial value = " << initialValue.i;
```

```
outputs:
initial value = 0
```

Fragment requirements

```
constexpr auto newValueFrag = fragment {
  requires std::string identifier;

  std::string newValue = identifier + " is cool";
};
```

Fragment requirements

```
constexpr auto newValueFrag = fragment {
  requires std::string identifier;

  std::string newValue = identifier + " is cool";
};

std::string identifier = "metaprogramming";
```

Fragment requirements

```
constexpr auto newValueFrag = fragment {
  requires std::string identifier;

  std::string newValue = identifier + " is cool";
};

std::string identifier = "metaprogramming";

consteval -> newValueFrag;
std::cout << newValue;
```

```
outputs:
metaprogramming is cool
```

Fragments

- block fragment
- namespace fragment
- class fragment (used for metaclasses)
- enum fragment

Class fragment

```
consteval void makeNonCopyable() {
  -> fragment struct T {
    T(const T&) = delete;
    T &operator=(const T&) = delete;
  };
}
```

Class fragment

```
consteval void makeNonCopyable() {
  -> fragment struct T {
    T(const T&) = delete;
    T &operator=(const T&) = delete;
  };
}
```

Class fragment

```
struct NonCopyable {
  consteval { makeNonCopyable(); }
};
```

```
struct NonCopyable {
  NonCopyable(const NonCopyable &) = delete;
  NonCopyable &operator=(const NonCopyable &) = delete;
};
```

```
static_assert(!std::is_copy_constructible_v<NonCopyable> && !std::is_copy_assignable_v<NonCopyable>); // ✔
static_assert(!std::is_move_constructible_v<NonCopyable> && !std::is_move_assignable_v<NonCopyable>); // ✔
```

Class fragment

```
consteval void makeMovable() {
  -> fragment struct T {
    T(T&&) = default;
    T &operator=(T&&) = default;
  };
}
```

Class fragment

```
struct MovableNonCopyable {
  consteval {
    makeNonCopyable();
    makeMovable();
  }
};
```

Class fragment

```
struct MovableNonCopyable {
  consteval {
    makeNonCopyable();
    makeMovable();
  }
};
```

```
struct MovableNonCopyable {
  MovableNonCopyable(const MovableNonCopyable&) = delete;
  MovableNonCopyable &operator=(const MovableNonCopyable&) = delete;
  MovableNonCopyable(MovableNonCopyable&&) = default;
  MovableNonCopyable &operator=(MovableNonCopyable&&) = default;
};
```

Class fragment

```
struct MovableNonCopyable {
  consteval {
    makeNonCopyable();
    makeMovable();
  }
};
```

```
struct MovableNonCopyable {
  MovableNonCopyable(const MovableNonCopyable&) = delete;
  MovableNonCopyable &operator=(const MovableNonCopyable&) = delete;
  MovableNonCopyable(MovableNonCopyable&&) = default;
  MovableNonCopyable &operator=(MovableNonCopyable&&) = default;
};
```

Enum fragment

```
consteval void injectBitMask(const char *name,
                             size_t value) {
  -> fragment enum {
    unqualid(%{ name }) = %{ value },
  };
}
```

Enum fragment

```
consteval void injectBitMask(const char *name,
                             size_t value) {
  -> fragment enum {
    unqualid(%{ name }) = %{ value },
  };
}
template<typename... T>
  requires (std::is_same_v<T, const char *> && ...)
consteval void generateBitMasks(T... names) {
  size_t counter = 0;
  (injectBitMask(names, 1 << counter++), ...);
}
```

Enum fragment

```
consteval void injectBitMask(const char *name,
                             size_t value) {
  -> fragment enum {
    unqualid(%{ name }) = %{ value },
  };
}
template<typename... T>
  requires (std::is_same_v<T, const char *> && ...)
consteval void generateBitMasks(T... names) {
  size_t counter = 0;
  (injectBitMask(names, 1 << counter++), ...);
}
```

Enum fragment

```
enum class BitMask {
  consteval { generateBitMasks("Foo", "Bar", "Baz"); }
  All = ~0
};
```

```
enum class BitMask : int {
  Foo = 1 << 0,
  Bar = 1 << 1,
  Baz = 1 << 2,
  All = ~0
};
```

Enum fragment

```
enum class BitMask {
  consteval { generateBitMasks("Foo", "Bar", "Baz"); }

};
```

```
enum class BitMask : int {
  Foo = 1 << 0,
  Bar = 1 << 1,
  Baz = 1 << 2,

};
```

Namespace fragment

```
template<Enumeration Enum>
consteval void defineBitwiseOperations() {
  -> fragment namespace {
    Enum operator|(Enum a, Enum b) {
      using T = std::underlying_type_t<Enum>;
      return static_cast<Enum>(static_cast<T>(a) | static_cast<T>(b));
    }
    Enum operator&(Enum a, Enum b) {
      using T = std::underlying_type_t<Enum>;
      return static_cast<Enum>(static_cast<T>(a) & static_cast<T>(b));
    }
  };
}
```

Namespace fragment

```
template<Enumeration Enum>
consteval void defineBitwiseOperations() {
  -> fragment namespace {
    Enum operator|(Enum a, Enum b) {
      using T = std::underlying_type_t<Enum>;
      return static_cast<Enum>(static_cast<T>(a) | static_cast<T>(b));
    }
    Enum operator&(Enum a, Enum b) {
      using T = std::underlying_type_t<Enum>;
      return static_cast<Enum>(static_cast<T>(a) & static_cast<T>(b));
    }
  };
}
```

Namespace fragment

```
enum class BitMask {
  consteval { generateBitMasks("Foo", "Bar", "Baz"); }
  All = ~0
};
```

Namespace fragment

```
enum class BitMask {
  consteval { generateBitMasks("Foo", "Bar", "Baz"); }
  All = ~0
};

consteval { defineBitwiseOperations<BitMask>(); }
```

Namespace fragment

```
enum class BitMask {
  consteval { generateBitMasks("Foo", "Bar", "Baz"); }
  All = ~0
};

consteval { defineBitwiseOperations<BitMask>(); }


const auto val = BitMask::Foo | BitMask::Bar;
```

More metaprogramming

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        requires Enum value;
        if (value == valueof(%{ member }))
          return meta::name_of(%{ member });
      };
  }
  return {};
}
```

More metaprogramming

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        requires Enum value;
        if (value == valueof(%{ member }))
          return meta::name_of(%{ member });
      };
  }
  return {};
}
```

More metaprogramming

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        requires Enum value;
        if (value == valueof(%{ member }))
          return meta::name_of(%{ member });
      };
  }
  return {};
}
```

More metaprogramming

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        requires Enum value;
        if (value == valueof(%{ member }))
          return meta::name_of(%{ member });
      };
  }
  return {};
}
```

More metaprogramming

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        requires Enum value;
        if (value == valueof(%{ member }))
          return meta::name_of(%{ member });
      };
  }
  return {};
}
```

does not currently work

More metaprogramming — janky workaround

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    auto valueInfo = reflexpr(value);
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        const auto name = meta::name_of(%{ member });
        if (idexpr(%{ valueInfo }) == valueof(%{ member }))
          return name;
      };
  }
  return {};
}
```

More metaprogramming — janky workaround

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    auto valueInfo = reflexpr(value);
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        const auto name = meta::name_of(%{ member });
        if (idexpr(%{ valueInfo }) == valueof(%{ member }))
          return name;
      };
  }
  return {};
}
```

More metaprogramming — janky workaround

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    auto valueInfo = reflexpr(value);
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        const auto name = meta::name_of(%{ member });
        if (idexpr(%{ valueInfo }) == valueof(%{ member }))
          return name;
      };
  }
  return {};
}
```

More metaprogramming — janky workaround

```
template<typename Enum>
std::string_view toString(Enum value) {
  consteval {
    auto valueInfo = reflexpr(value);
    for (auto member : meta::members_of(reflexpr(Enum)))
      -> fragment {
        const auto name = meta::name_of(%{ member });
        if (idexpr(%{ valueInfo }) == valueof(%{ member }))
          return name;
      };
  }
  return {};
}
```

Assembling it all together — serialization

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  using Type = std::decay_t<T>;
  consteval {
    for (auto m : meta::data_member_range(reflexpr(Type)))
      -> fragment {
        requires Visitor &&visit;
        requires T &&value;
        visit(value.idexpr(%{ m }), meta::name_of(%{ m }));
      };
  }
}
```

Assembling it all together — serialization

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  using Type = std::decay_t<T>;
  consteval {
    for (auto m : meta::data_member_range(reflexpr(Type)))
      -> fragment {
        requires Visitor &&visit;
        requires T &&value;
        visit(value.idexpr(%{ m }), meta::name_of(%{ m }));
      };
  }
}
```

Assembling it all together — serialization

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  using Type = std::decay_t<T>;
  consteval {
    for (auto m : meta::data_member_range(reflexpr(Type)))
      -> fragment {
        requires Visitor &&visit;
        requires T &&value;
        visit(value.idexpr(%{ m }), meta::name_of(%{ m }));
      };
  }
}
```

Assembling it all together — serialization

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  using Type = std::decay_t<T>;
  consteval {
    for (auto m : meta::data_member_range(reflexpr(Type)))
      -> fragment {
        requires Visitor &&visit;
        requires T &&value;
        visit(value.idexpr(%{ m }), meta::name_of(%{ m }));
      };
  }
}
```

Assembling it all together — serialization

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  using Type = std::decay_t<T>;
  consteval {
    for (auto m : meta::data_member_range(reflexpr(Type)))
      -> fragment {
        requires Visitor &&visit;
        requires T &&value;
        visit(value.idexpr(%{ m }), meta::name_of(%{ m }));
      };
  }
}
```

does not currently work

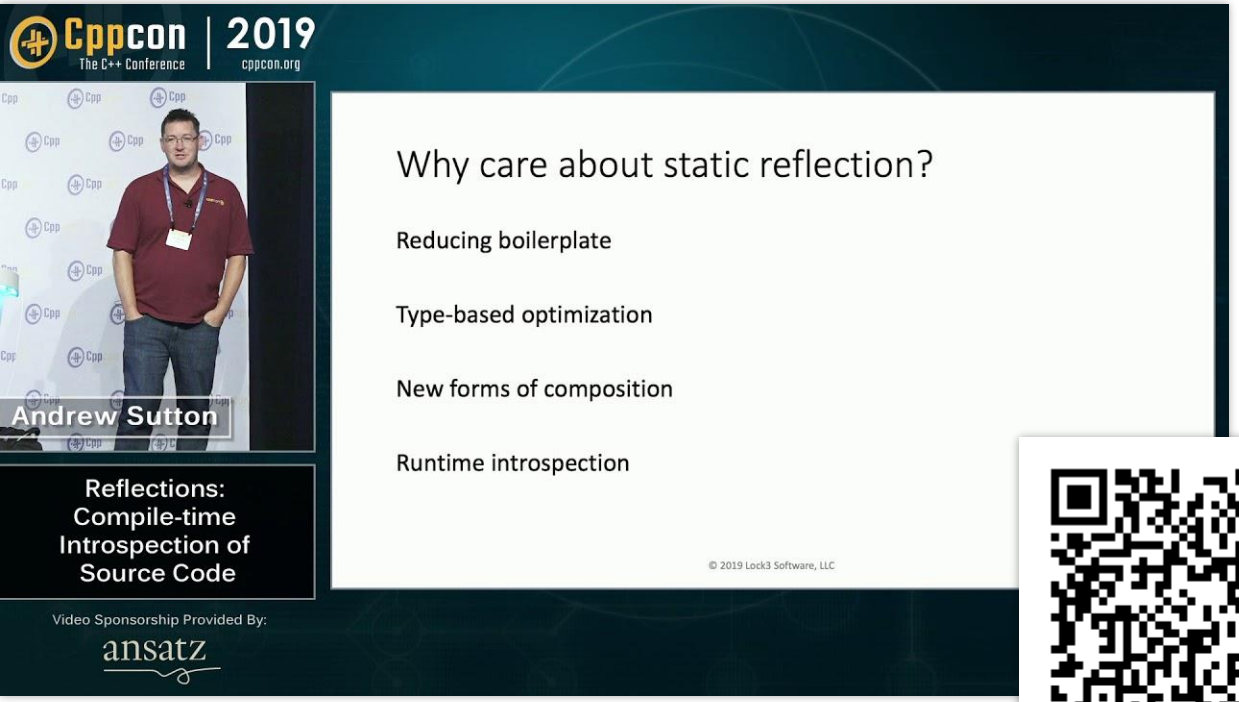
Assembling it all together — janky workaround

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  using Type = std::decay_t<T>;
  consteval {
    auto visitInfo = reflexpr(visit); // workaround
    auto valueInfo = reflexpr(value);
    for (auto m : meta::data_member_range(reflexpr(Type)))
      -> fragment {
        { // workaround
          auto &visit = idexpr(%{ visitInfo });
          const auto &value = idexpr(%{ valueInfo });
          const auto &field = value.idexpr(%{ m });
          const auto name = meta::name_of(%{ m });
          visit(field, name);
        }
      };
  }
}
```

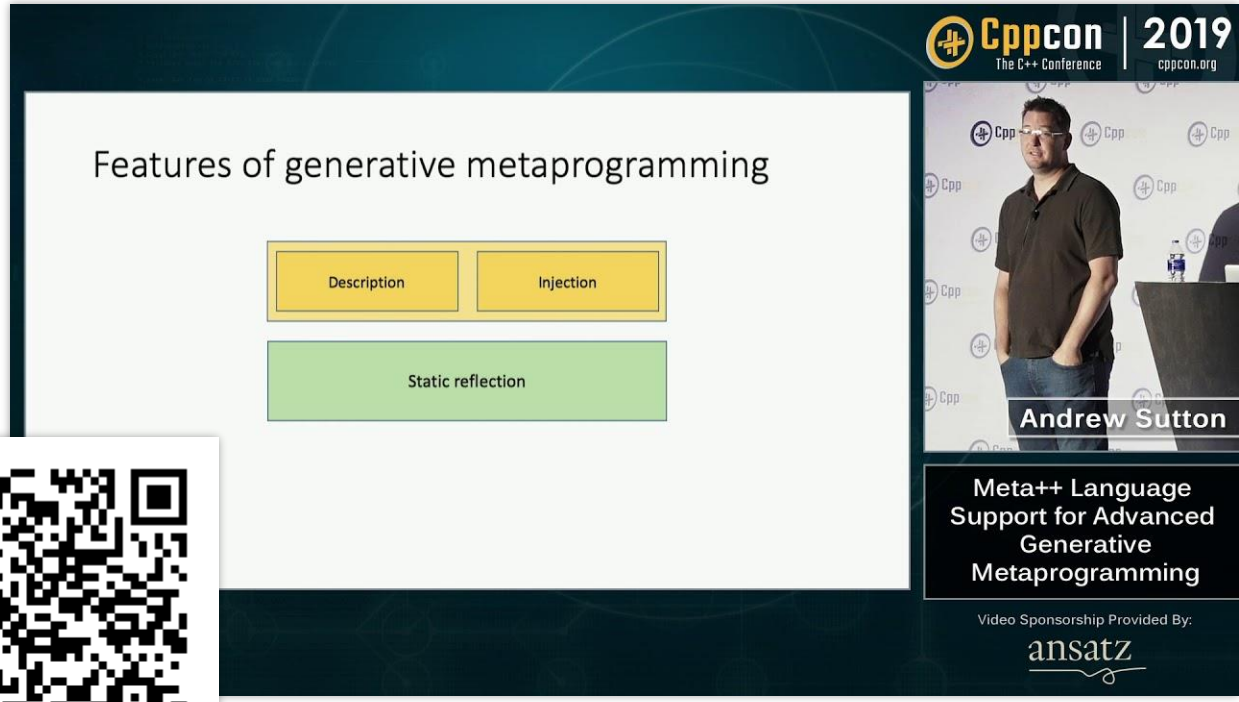
https://cppx.godbolt.org/

Proposal in the C++ standard P1717: https://wg21.link/p1717

https://youtu.be/ARxj3dfF_h0



https://youtu.be/kjQXhuPX-Ac



Metaprogramming is coming... kinda

Pavel Novikov

@cpp_ape

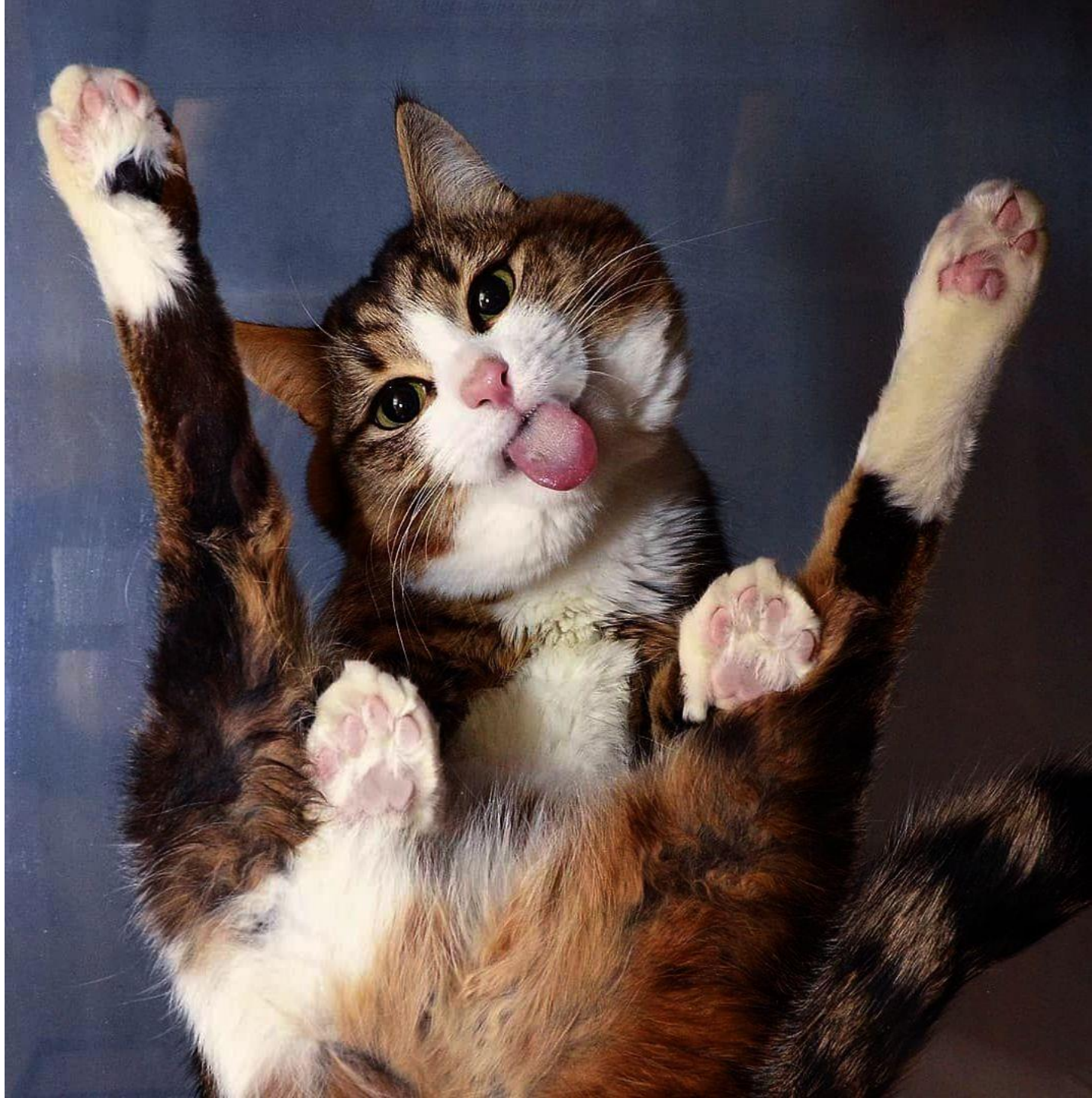
Align Technology R&D

align

Thanks to Wyatt Childers for feedback!

Slides: https://git.io/JJ3dJ

Bonus slides



Metaclasses

```
consteval void AddTextMember(meta::info type) {
  for (auto m : meta::member_range(type))
    ->m;

  -> fragment struct {
    std::string text;
  };
}

struct(AddTextMember) AddedMember {};
```

```
struct AddedMember {
  std::string text;
};
```

Metaclasses

```
consteval void Interface(meta::info type) {
  bool needDtor = true;
  for (auto m : meta::member_range(type)) {
    if (meta::is_data_member(m))
      meta::compiler.error("an interface can not contain data members");
    if (meta::is_destructor(m)) {
      needDtor = false;
      meta::make_virtual(m);
    }
    else if (meta::is_nonstatic_member_function(m) && !meta::is_defined(m)) {
      meta::make_pure_virtual(m);
    }
    -> m;
  }
  if (needDtor) {
    -> fragment struct T {
      virtual ~T() = default;
    };
  }
}
```

Metaclasses

```
struct(Interface) Cat {
  void meow();
  void purr();
};
```

```
struct Cat {
  virtual ~Cat() = default;
  virtual void meow() = 0;
  virtual void purr() = 0;
};
```

Metaprogramming as of December 2019

Metaprogramming

- injection
- fragments
- metaprograms

Injection

```
consteval -> ...
```

Injection

```
namespace a {
  int value = 42;
}

namespace b {
  consteval -> reflexpr(a::value);
}
```

Injection

```
namespace a {
   int value = 42;
}

namespace b {
   consteval int value_of(){ return a::value; }
   int value = 42;
}
```

Fragments

```
const auto fragment = __fragment {};
```

Fragments

```
const auto fragment = __fragment {};

consteval -> fragment;
```

Fragments

```
const auto fragment = __fragment {};

consteval -> fragment;


consteval -> __fragment {};
```

Fragments

```
consteval -> __fragment {
  std::string value = "injected variable";
};
```

Fragments

```
consteval -> __fragment {
  std::string value = "injected variable";
};
```

Fragments

- namespace fragment
- class fragment (used for metaclasses)
- enum fragment

Metaprograms

```
consteval {
  -> __fragment {
    std::string value = "injected variable";
  };
}
```

Metaprograms

```
void foo() {
  consteval {
    -> __fragment {
      std::string value = "injected variable";
    };
  }
  use(value);
}
```

Metaprograms

```
consteval void immediateFunction() {
  -> __fragment {
    std::string value = "injected variable";
  };
}

void foo() {
  consteval { immediateFunction(); }
  use(value);
}
```

More metaprogramming

```
template<typename Enum>
std::string toString(Enum value) {
  consteval {
    for (auto i : meta::members_of(reflexpr(Enum))
      -> __fragment {
        if (value == valueof(i))
          return meta::name_of(i);
      };
  }
  return "<unknown>";
}
```

More metaprogramming

```
template<typename Enum>
std::string toString(Enum value) {
  consteval {
    for (auto i : meta::members_of(reflexpr(Enum))
      -> __fragment {
        if (value == valueof(i))
          return meta::name_of(i);
      };
  }
  return "<unknown>";
}
```

Assembling it all together

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  consteval {
    auto type = reflexpr(std::decay_t<T>);
    for (auto m : meta::data_member_range(type)) {
      -> __fragment {
        visit(value.unqualid(meta::name_of(m)), meta::name_of(m));
      };
    }
  }
}
```

Assembling it all together

```
template<typename Visitor, typename T>
void iterateMembers(Visitor &&visit, T &&value) {
  consteval {
    auto type = reflexpr(std::decay_t<T>);
    for (auto m : meta::data_member_range(type)) {
      -> __fragment { { // workaround
          auto ptr = valueof(m);
          visit(value.*ptr, meta::name_of(m));
      } };
    }
  }
}
```