Meeting C++ 2017

Concepts Driven Design

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Overview

- **Concepts**
  - Motivation / History
- **Type constraints** (C++20)
  - Requirements
    - Design by introspection
  - Named concepts
    - Optional interfaces
- **Concepts emulation** (C++17)

- **Concepts based design**
  - Static polymorphism
  - Dynamic polymorphism
    - Virtual concepts (C++2?)
  - Dependency Injection
  - Mocking (testing)
- **Future of concepts** (C++2X)

Disclaimer

> This talk is from user perspective
> See Andrew Sutton talks for more details about concepts!

> Concepts, although, merged into C++20 draft, are still a subject for future changes

Compiler	Version	Notes
GCC	6.1+	Requires `-fconcepts` flag
MSVC	VS2017 15.5	-
Clang	In progress...	-

> Examples in this talk were compiled using
> `g++7.2 -std=c++2a -fconcepts`

Motivation - Well specified interfaces

```
template<class T>
constexpr const T& min(const T& a, const T& b) {
  return b < a ? b : a;
}
```

> Precise documentation

> - What's are the syntax requirements for `T`?
>   - compile-time / ***concepts***

> - What's are the semantics requirements for `min`?
>   - run-time / contracts, tests, manuals

Motivation - Compiler diagnostics

```
int main() {
  auto list = std::list{1, 2, 3};
  std::sort(std::begin(list), std::end(list));
}
```

https://godbolt.org/g/RTRgg2

Motivation - Compiler diagnostics

> Without concepts

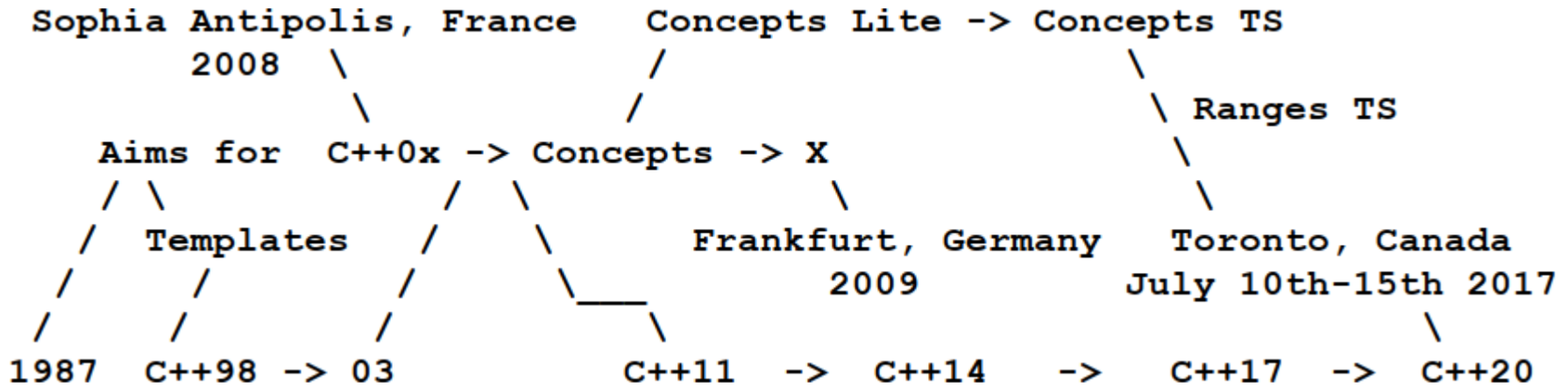
```
 invalid operands to binary expression
   ('std::_List_iterator<int>' and
    'std::_List_iterator<int>')
 std::__lg(__last - __first) * 2);
           ~~~~~~ ^ ~~~~~~~
...many lines of templates instantiation call stack...
```

> With concepts

```
error: cannot call std::sort
 note: concept RandomAccessIterator was not satisfied
since: expression (b-a) will be ill formed
```

> Note: Constraints are checked at the point of use

History



Requirements analysis	https://wg21.link/n3351
Concepts Lite	https://wg21.link/n3701
Concepts TS	https://wg21.link/P0734R0

> Bjarne Stroustrup, Andrew Sutton, Gabriel Dos Reis
> Alex Stepanow, Andrew Lumsdaine, Sean Parent, ...

C++20 draft

> Requirements
> Constraints
> Named concepts

http://eel.is/c++draft/temp.constr

Requirements

Requires-clause

> Specifies constraints on template arguments or on a function declaration
>
> `std::enable_if` on steroids

```
template<class> requires false
void foo() {}
```

```
foo<class AnyType>(); // Error: constraints not satisfied
```

```
template<bool Value> requires Value
void bar() {}
```

```
bar<true>();  // Okay
bar<false>(); // Error: constraints not satisfied
```

> Note: requires-clause is part of the function signature

Requires-expression

> Expression of type bool
>
> `requires ( [parameters] ) { requirements }`

```
// type requirement
requires(T) { typename T::value_type;  }; // type has to be accessible/visible
```

```
// simple requirement
requires(T t) { t[typename T::value_type{}]; };
```

```
// compound requirement
requires(T t) { { t.empty() } -> bool; }; // convertible to bool
```

```
// nested requirement
requires(T t) { requires std::is_enum_v<typename T::value_type>; };
```

> Note: Parameters -> `declvals` (converts any type to a reference type)

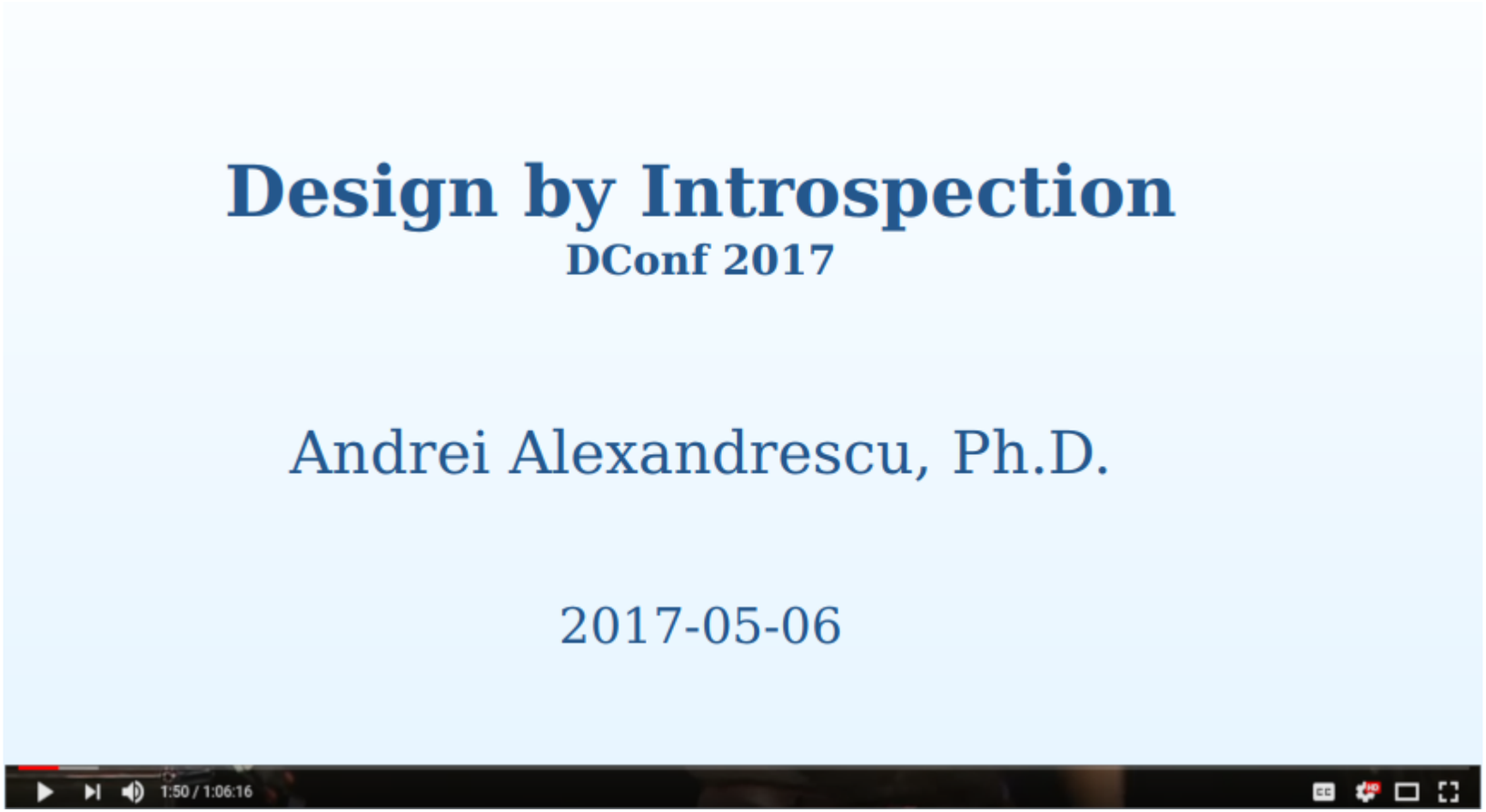
Requires-clause/Requires-expression

```
template<class T>
constexpr auto foo(T&& x) // immediate context (SFINAE friendly)
  requires requires(T t) { t.bar(); }
{ return x.bar(); }
```

```
  struct { void bar() {} } bar;
  foo(bar); // Okay
  foo(42);  // Error: constraints not satisfied
            //  note: the required expression
            //        't.bar()' would be ill-formed
```

> Note: `requires requires` -> `requires-clause` followed by `requires-expression`

Design by introspection



https://www.youtube.com/watch?v=29h6jGtZD-U

Design by introspection - D lang

> https://dlang.org/spec/traits.html

```
auto foo(T)(T x) {
  static if(__traits(hasMember, x, "bar")) {
    return x.bar;
  } else {
    return 0;
  }
}

void main() {
  assert(0 == foo(42));

  struct Bar { int bar = 42; }
  Bar bar;
  assert(42 == foo(bar));
}
```

https://godbolt.org/g/wpLXzV

Design by introspection - C++20

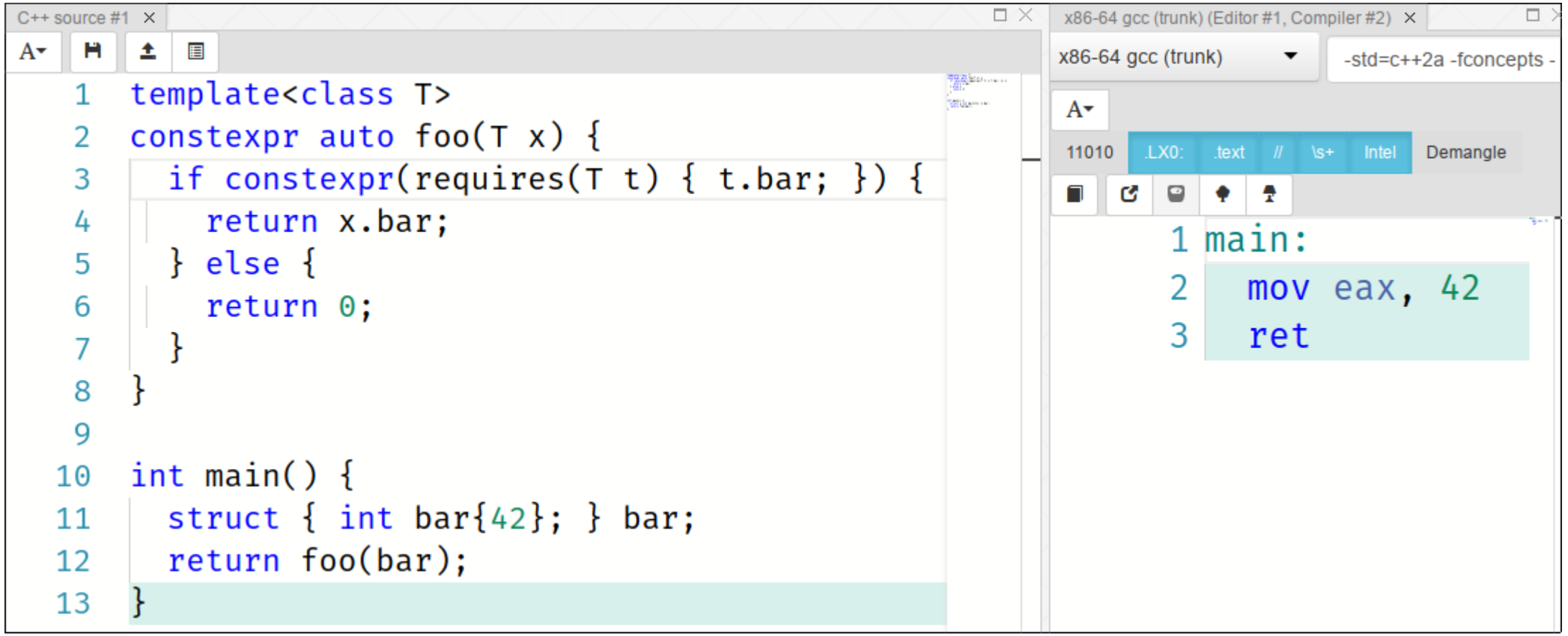
```
template<class T>
constexpr auto foo(T x) {
  if constexpr(requires(T t) { t.bar; }) {
    return x.bar;
  } else {
    return 0;
  }
}

int main() {
  assert(0 == foo(42));

  struct { int bar{42}; } bar;
  assert(42 == foo(bar));
}
```

https://godbolt.org/g/uot6Bv

Design by introspection - C++



https://godbolt.org/g/MFxqWu

Requirements

> Readability?

```
template<class T>
class Bar
  requires requires(T t) {
    typename T::type;
    { t.foo() } -> void;
    requires Movable<T> or Same<T, int>;
  };
```

Named concepts

Named concepts

> A collection of requirements on a type (variable template)

```
template<template-parameters>
concept concept-name = constraint-expression;
```

> "If you like it then you should have put a name on it", Beyonce rule

Named concepts

> Predicate constraints

```
template<class>
concept Always = true; // always satisified
```

```
template<class T>
concept Size32 = sizeof(T) == 4;
```

> Conjunctions, Disjunctions

```
template<class T>
concept SignedIntegral = std::is_integral_v<T> and std::is_signed_v<T>;
```

Named concepts

> Requirements

```
template<class T>
concept Fooable =              // named concept
  requires(T t) {              // collection of
    typename T::type;          //   type requirement
    { t.foo() } -> void;       //   compound requirement
    requires Movable<T> or     //   nested requirement
             Same<T, int>;
  };
```

> Note: Concepts are never instantiatied
>
> (therefore the `concept` keyword)

Named concepts

> Unconstrained class definition

```
template<class> class Bar {};
```

> Requires expression (long form)

```
template<class T> requires Fooable<T> class Bar { };
```

> Abbreviated templates

```
template<Fooable T> class Bar {};
```

> Note: More simplifying syntaxes to come

Named concepts

> Example

```
struct tcp_socket { void send(std::string_view); };
struct udp_socket { void send(std::string_view); };
struct file       { void write(std::string_view); };
...
```

```
template<class T> void forward(T& t, std::string_view data) { // generic
  t.???(data); // send/write
}
```

> Everything Cpp
>
> https://www.youtube.com/watch?v=xsSYPD0v5Mg

Named concepts

> Concept definition

```
template<class T> concept Socket =
  requires(T t, std:string_view data) {
    { t.send(data) } -> void; // compound requirement
};
```

```
template<class T> concept File =
  requires(T t, std:string_view data) {
    { t.write(data) } -> void; // compound requirement
};
```

Named concepts

> Concept overloading

```
template<Socket T> // requires Socket<T>
/*1*/ void forward(T& t, std::string_view data) { t.send(data); }

template<File T> // requires File<T>
/*2*/ void forward(T& t, std::string_view data) { t.write(data); }
```

```
int main() {
 tcp_socket tcp; forward(tcp, "tcp data"sv); // calls 1
 udp_socket udp; forward(udp, "udp data"sv); // calls 1
 file file; forward(file, "file data"sv);    // calls 2
}
```

> Note: If multiple are satisifed the most constrainted is chosen

Named concepts

> Concepts overloading
>
> `if constexpr` (C++17)

```
template<class T>
void forward(T& t, std::string_view data) {
  if constexpr(Socket<T>) { // compile-time
    t.send(data);
  } else if constexpr(File<T>) {
    t.write(data);
  }
}
```

> Note: Branch which is not taken is discarded
>
> --------- Statement may not compile but syntax has to be valid

Named concepts

> `Lambdas`

```
constexpr auto forward =
  [](auto& t, std::string_view data) {
    using type = std::decay_t<decltype(t)>>;
    if constexpr(Socket<type>) { t.send(data);  } else
    if constexpr(File<type>)   { t.write(data); }
  };
```

> `Generic lambdas` (C++17) - https://wg21.link/P0428r2

```
constexpr auto forward =
  []<class T>(T& t, std::string_view data) {
    if constexpr(Socket<T>) { t.send(data);  } else
    if constexpr(File<T>)   { t.write(data); }
  };
```

`Named concepts`

> Optional interfaces

Example -> `Stream<T>`

- Copy constructible
- Printable
- Callable member function `write` which takes type `T&`
- Callable member function `read` which returns type `T`
- Callable either with a member function `read_complete` or `commit_read`

Named concepts

> Optional interfaces : Inheritance / virtual functions (not expressive enough)

```
/**
 * Implementation requires to be printable and
 * copy constructible
 */
template<class T>
class istream {
public:
  virtual ~istream() noexcept = default;
  virtual void write(T&) = 0;
  virtual T read() = 0;

  /// ??? one of
  virtual void read_complete() = 0;
  virtual void commit_read() = 0;
};
```

Named concepts

> Optional interfaces : Concepts

```
template<class T, class TData>
concept Streamable =
  CopyConstructible<T> and          // CopyConstructible
  requires(T t, std::ostream& out, TData& data) {
    out << t;                       // Printable
    t.write(data);                  // Writable
    { t.read() } -> TData;          // Readable
    t.commit_read();                // Readable 2/2
  } or requires(T t, std::ostream& out, TData& data) {
    out << t;                       // Printable
    t.write(data);                  // Writable
    { t.read() } -> TData;          // Readable 1/2
    t.read_complete();              // Readable 2/2
  }
};
```

Named concepts

> Optional interfaces : Usage

```
using data_t = std::array<std::byte, 1024>;
```

```
class FileStream {
public:
  void write(data_t&);
  data_t read();
  void commit_read();
};
```

```
class MemoryStream {
public:
  void write(data_t&);
  data_t read();
  void read_complete();
};
```

```
int main() {
  Streamable<data_t> stream = FileStream/MemoryStream{};
  const auto data = stream.read();
  ...
  stream.commit_read/read_complete();
}
```

Placeholders

```
template<class T> concept Fooable = true;
template<class T> struct Foo { Foo(T); };
```

```
auto     foo1 = Foo{42}; // C++11 - auto -> least constrained concept
Foo      foo2 = Foo{42}; // C++17 - Constructor Template Argument Deduction
Fooable foo3 = Foo{42}; // C++20 - placeholder
```

> Note: C++17 - Non-type template arguments

```
template<auto T> class Bar {}; // For values -> Bar<42>
```

> Note: Placeholders can be used for functions `void f(auto);`

Concepts in the C++ ISO standard

> Note: More concepts to come with Ranges TS

Concepts and the C++ ISO standard

Table 18 — `EqualityComparable` requirements [**equalitycomparable**]

Expression	Return type	Requirement
`a == b`	convertible to `bool`	`==` is an equivalence relation, that is, it has the following properties: — For all `a`, `a == a`. — If `a == b`, then `b == a`. — If `a == b` and `b == c`, then `a == c`.

```
template<class T> // C++20 concepts
concept EqualityComparable = requires(T a, T b) {
  { a == b } -> bool;
};
```

```
class EqualityComparable a where // Haskell typeclasses
  (==) :: a -> a -> Bool
```

Concepts - Ranges TS

```
template <class I>
concept InputIterator =
  Iterator<I> &&
  Readable<I> &&
  requires(I& i, const I& ci) {
      typename iterator_category_t<I>;
      DerivedFrom<
        iterator_category_t<I>, input_iterator_tag>;
      i++;
  };
```

https://github.com/CaseyCarter/cmcstl2

Concepts emulation (C++17)

Concepts emulation (C++17)

> Substituation Failure Is Not An Error (SFINAE)

```
template<bool, class = void>
struct enable_if {}; // no type alias

template<class T>
struct enable_if<true, T> { using type = T; };
```

- `false` predicates lead to ill-formed code that's discarded

Concepts emulation (C++17)

> Dedection idiom (C++17)

```
template<class T>
using Fooable = decltype(std::declval<T&>().foo());
```

```
struct Foo { void foo(); };
struct Bar { };
```

```
static_assert(not std::is_detected<Fooable, Bar>{});
static_assert(    std::is_detected<Fooable, Foo>{});
```

> Note: Under the hood, it uses
>
> `template<class...> using void_t = void;`

https://wg21.link/n4436

Concepts emulation (C++17)

> Does the Concepts TS Improve on C++17?

```
template <class F, class... Args, class =  decltype(
  std::declval<F&&>()(std::declval<Args&&>()...))> // if is well-formed return
constexpr auto requires_impl(int) { return true; } // true otherwise remove
                                                   // the candidate from the
                                                   // overload set

template <class...>
constexpr auto requires_impl(...) { return false; } // the last man standing
                                                    // return false


template <class... Args, class F>
constexpr auto requires(F&&) {
  return requires_impl<F&&, Args&&...>(int{});
}
```

https://wg21.link/P0726R0

Concepts emulation (C++17)

> `requires-clause`

```
struct Foo { void foo(); };
struct Bar {};
```

```
static_assert(
  requires<Foo>([](auto&& t) -> decltype(t.foo()) {})
);

static_assert(
  !requires<Bar>([](auto&& t) -> decltype(t.foo()) {})
);
```

Concepts emulation (C++17)

> Design by introspection - C++17

```
template<class T> constexpr auto foo(T x) {
  if constexpr(requires<T>( // compile-time if
   [](auto&& t) -> decltype(t.bar) {})) {
    return x.bar;
   } else {
    return 0;
  }
}
```

> Note: Workaround for expression is not a constant expression

```
 if constexpr(
   auto bar = [](auto&& t) -> decltype(t.bar) {};
   requires<T>(bar)
 )
```

Concepts emulation (C++17)

> Named concept

```
template<class T> constexpr auto Socket =
  requires<T>([](auto&& t, std:string_view data)->
    decltype(t.send(data)) {}
  );
```

```
template<class T> constexpr auto File =
  requires<T>([](auto&& t, std:string_view data) ->
    decltype(t.write(data)) {}
  );
```

Concepts emulation (C++17)

> Error message

```
template<class T, class = std::enable_if_t<Socket<T>>
void forward(T& t, std::string_view data) {
  t.send(data);
}
```

```
int main() {
  tcp_socket tcp; forward(tcp, "tcp data"sv); // Okay
  file file; forward(file, "file data"sv);
   // error: no matching function for call to 'forward'
   // possibly many lines of output <- library side
}
```

> Note: No details why function couldn't be called

Concepts emulation (C++17)

> Concepts overloading

```
template<class T, std::enable_if_t<Socket<T>, int> = 0>
/*1*/ void forward(T& t, std::string_view data) { t.send(data); }

template<class T  std::enable_if_t<File<T>, int> = 0>
/*2*/ void forward(T& t, std::string_view data) { t.write(data); }
```

```
int main() {
 tcp_socket tcp; forward(tcp, "tcp data"sv); // calls 1
 udp_socket udp; forward(udp, "udp data"sv); // calls 1
 file file; forward(file, "file data"sv);    // calls 2
}
```

> Note: Default template pramaters aren't part of the function signature (no SFINAE)

Concepts emulation (C++17)

> Concept overloading
>
> `if constexpr` (C++17)

```
template<class T>
void forward(T& t, std::string_view data) {
  if constexpr(Socket<T>) { // compile-time
    t.send(data);
  } else if constexpr(File<T>) {
    t.write(data);
  }
}
```

> Note: Exactly the same way as with C++20 concepts

Concepts based design

Concepts based design

> Goals

Expressiveness	Type constraints for better error messages
Loosely coupeled design	Inject all the things! (Policy Design)
Performance	Static dispatch by default (based on concepts)
Flexiblity	Dynamic dispatch using type-erasure (based on the same concepts)
Testability	Automatic mocks injection (based on the same concepts)

Concepts based design

> Static polymorphism

```
template<class T> concept Drawable =
  requires(T t, std::ostream& out) { { t.draw(out) } -> void; };
```

```
struct Square { void draw(std::ostream& out) { out << "Square"; } };
struct Circle { void draw(std::ostream& out) { out << "Circle"; } };

template<Drawable T>
void print(T const& d) { d.draw(std::cout); }

int main() {
  print(Square{}); // prints Square
  print(Circle{}); // prints Circle
}
```

Concepts based design

> Static polymorphism

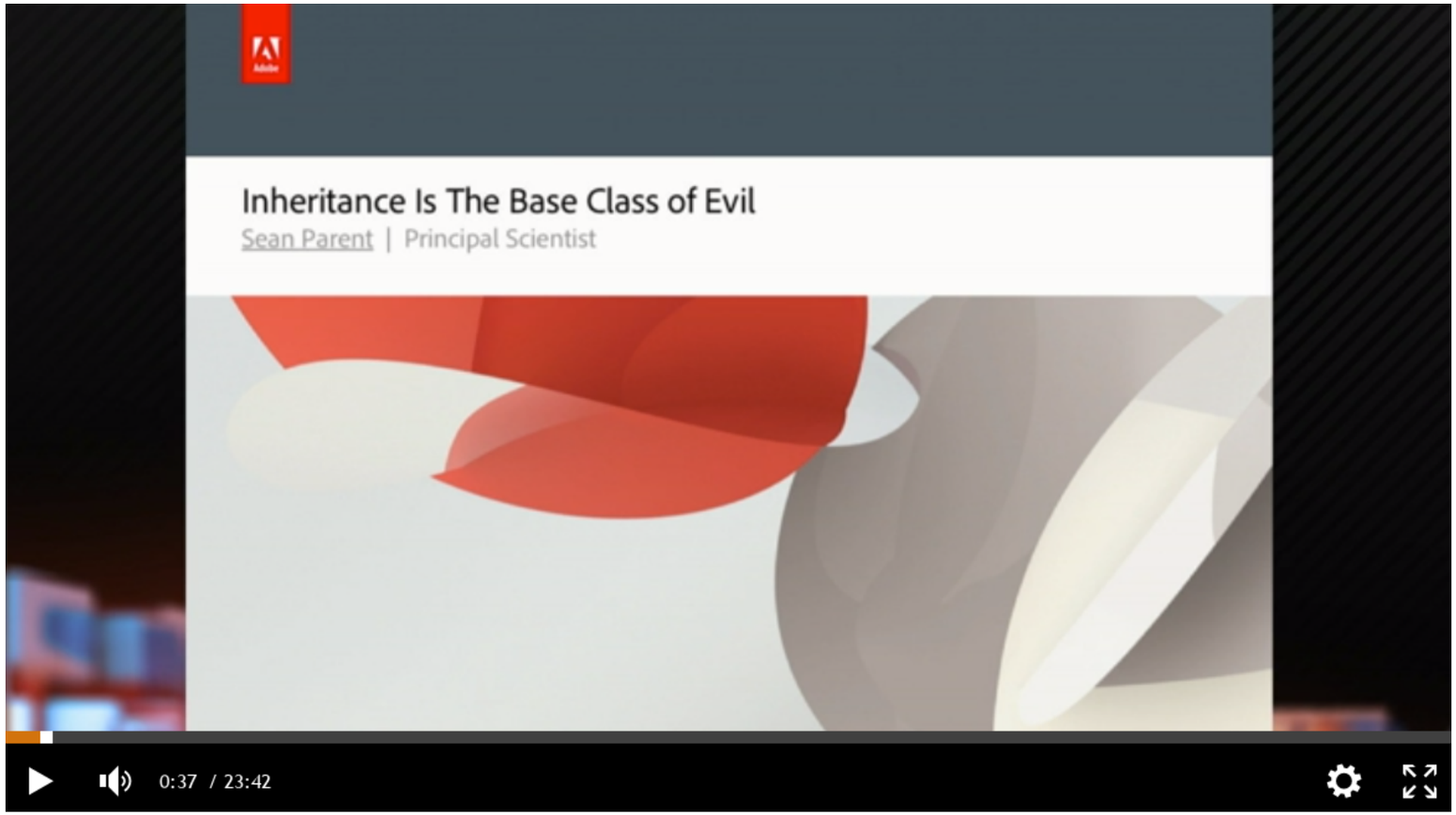
```
std::vector v1 = { Square{}, Circle{} };
 // ERROR: class template argument deduction failed

std::vector<auto> v2 = { Square{}, Circle{} };
 // ERROR: couldn't deduce template parameter

std::vector<Drawable> v3 = { Square{}, Circle{} };
 // ERROR: couldn't deduce template parameter
```

Concepts based design

> Concepts based polymorphism / Dynamic polymorphism



Inheritance-Is-The-Base-Class-of-Evil

Concepts based design

> Dynamic polymorphism / type-erasure

```
class Drawable {
  void* ptr_{}; // ??? Small Buffer Optimization (SBO)
  struct {
    void (*draw)(void*, std::ostream&);
    void (*delete_ptr)(void*);
  } const vptr_{}; // ??? Usually a pointer

public:
 template<class T> Drawable(T t) // non explicit
  : ptr_{new T{t}}, vptr_{
      [](void* self, std::ostream& os) { static_cast<T*>(self)->draw(os); },
      [](void* self) { delete static_cast<T*>(self); }
    } { }
 ~Drawable() { vptr_.delete_ptr(ptr_); }

 void draw(std::ostream& os) { vptr_.draw(ptr_, os); }
};
```

Concepts based design

> Dynamic polymorphism / type-erasure

```
void print(Drawable const& d) { d.draw(std::cout); }

int main() {
  print(Square{}); // prints Square
  print(Circle{}); // prints Circle
}
```

```
std::vector<Drawable> v; // Okay
v.push_back(Square{});   // Okay
v.push_back(Circle{});   // Okay
```

Concepts based design

> Dynamic polymorphism / Virtual concepts (C++2?) - Dynamic Generic Programming with Virtual Concepts

```
template<class T> concept Drawable =
  requires() { auto T::draw(std::ostream&) -> void; };
             // Signature requirement
```

```
struct Square { void draw(std::ostream& out) { out << "Square"; } };
struct Circle { void draw(std::ostream& out) { out << "Circle"; } };

void print(virtual Drawable const& d) { d.draw(std::cout); }
     // ~~~^~~~~ type-erasure

int main() {
  print(Square{}); // prints Square
  print(Circle{}); // prints Circle
}
```

Concepts based design

> Dynamic polymorphism / Virtual concepts (C++2?)

```
std::vector<virtual Drawable> v; // Okay (type-erasure)
v.push_back(Square{});           // Okay
v.push_back(Circle{});           // Okay
```

> No inheritance
>
> No heap
>
> 100% value semantics
>
> Might be inlined (Small buffer optimization - SBO)

Concepts based design

> Dynamic polymorphism / Metaclasses (C++2?) - https://wg21.link/p0707r0

```
any Square { void draw(std::ostream& out) { out << "Square"; } };
```

```
$class any { // type-erasure metaclass
  void* ptr_{};
  struct {
    constexpr {
      void (*delete_ptr)(void*);
      for... (const auto f: $any.functions()) {
        -> {
          idexpr(f).ret_type() (*idexpr(f)())(void*, idexpr(f).args());
        }
      }
    }
  } const vptr_{};
  ...
};
```

Concepts based design

> Dynamic polymorphism / Virtual concepts emulation (C++17)

```
template<class T> constexpr auto Drawable =
  Callable<void(T::*)(std::ostream&)>( $((draw)) );
```

```
struct Square { void draw(std::ostream& out) { out << "Square"; } };
struct Circle { void draw(std::ostream& out) { out << "Circle"; } };

void print(any<$(Drawable)> const& d) { d.draw(std::cout); }

int main() {
  print(Square{}); // prints Square
  print(Circle{}); // prints Circle
}
```

Concepts based design

> Virtual concepts emulation (C++17)

```
Callable<void(T::*)(std::ostream&)>( $((draw)) ]
          \_  \________     \_________    \___-> name
            \           \               \
$((name)) [](auto&& r, auto&& t, auto&&... args) {
 struct { // base class
  auto name(decltype(args)... args)  ->
    decltype(self.name(args...)){} {
   // static polymorphism (CRTP)
   return static_cast<decltype(t) *>(this)->template
     call<name, typename decltype(r)::type>(args...);
  }
 } _; return _;
}
```

```
$(type) decltype(type<...>)
```

https://github.com/boost-experimental/vc

Concepts based design

> Dependency Injection (`policy design`) / `concepts`

```
template<class T>
concept ErrorPolicy =
  requires(T t, std::string_view msg) {
    requires CopyConstructible<T>;
    { t.onError(msg) } -> void;
};
```

```
struct ThrowPolicy {
  void onError(std::string_view msg) { throw T{msg}; }
};

struct LogPolicy {
  void onError(std::string_view msg) {  std::clog << T{msg} << '\n'; }
};
```

Concepts based design

> Dependency Injection (`policy design`) / `concepts`

```
template<ErrorPolicy TPolicy = class Policy> // inject
struct App {
  TPolicy policy{};
  void run() { if (...) { policy.onError("error!"); } }
};
```

> Bindings / Injection

```
Creatable injector = di::injector{
  di::bind<class Policy>.to<ThrowPolicy>()
};
injector.create<App>().run();
```

> Same as...

```
App{ThrowPolicy{}}.run();
```

Concepts based design

> Dependency Injection (`policy design`) / `virtual concepts (C++2?)`

```
class App {
public:
 explicit App(virtual ErrorPolicy policy)
  : policy{policy}
 { }

  void run() {
    if (...) { policy.onError("error!"); }
  }

private:
 virtual ErrorPolicy policy{};
};
```

Concepts based design

> Dependency Injection (`policy design`) / `virtual concepts (C++2?)`

```
Creatable injector = di::make_injector(
  di::bind<virtual ErrorPolicy>.to<LogPolicy>()
);
injector.create<App>().run();
```

> Same as...

```
App{LogPolicy{}}.run();
```

https://github.com/boost-experimental/di

Concepts based design

> Dependency Injection (`policy design`) / `virtual concepts emulation (C++17)`

```
template<class T>
constexpr auto ErrorPolicy =
  CopyConstructible<T> and Callable<void(T::*)()>( $((onError)) ); // expose
```

```
struct App {
  any<$(ErrorPolicy)> policy{};
  void run() { if (...) { policy.onError("error!"); } }
};
```

Concepts based design

> Dependency Injection (`policy design`) / `virtual concepts emulation (C++17)`

```
Creatable injector = di::make_injector(
  di::bind<$(ErrorPolicy)>.to<LogPolicy>()
);
injector.create<App>().run();
```

> Same as...

```
App{LogPolicy{}}.run();
```

> Note: Same wiring for static/dynamic polymorphism

Concepts based design

> Mocking (testing)

> Interface based mocking

```
struct ErrorPolicy {
 virtual ~ErrorPolicy() = default;
 virtual void onError(std::string_view) = 0;
};
GMock<ErrorPolicy> mock{};
EXPECT_CALL(mock, onError("interface!")).Times(1);
mock.onError("interface!");
```

> Concepts based mocking

```
GMock<$(ErrorPolicy)> mock{};
EXPECT_CALL(mock, onError("concept!")).Times(1);
object(mock).onError("concept!");
```

Concepts based design

> Mocking (testing)

> `automatic mocks injection`

```
"should print read text"_test = [] {
 auto [app, mocks] = testing::make<App>();

 EXPECT_CALL(mocks<$(ErrorPolicy)>, onError("error!"));

 app.run();
};
```

> Note: `make` creates mocks based on concepts requirements (reflection)

https://github.com/cpp-testing/gunit

Future of concepts (C++2X)

Future of concepts (C++2X)

> Terse template syntax

```
void forward(Socket& socket, std::string_view data);
```

> long form

```
template<Socket T>
void forward(T& socket, std::string_view data);
```

> longer form

```
template<class T> requires Socket<T>
void forward(T& socket, std::string_view data);
```

Future of concepts (C++2X)

> Terse template syntax - https://wg21.link/p0696r1

```
void forward(Socket, Socket);
```

> long form

```
template<class T> void forward(T, T);
```

> **vs**

```
void forward(auto, auto);
```

> long form

```
template<class T, class U> void forward(T, U);
```

Future of concepts (C++2X)

> Template-introduction syntax

```
Socket{T} void forward(T, auto);
```

> **or**

```
template<Socket [T]> void forward(T, auto);
```

> long form

```
template<class T, class U> void forward(T, U) requires Socket<T>;
```

Future of concepts (C++2X)

```
template<class T>
struct tcp_socket {
  static_assert(Socket<tcp_socket>); // always fail, tcp_socket is incomplete
};
```

> Metaclasses syntax

```
template<class T> Socket tcp_socket { };
```

https://wg21.link/p0707r0

Summary

> Allows well specified interfaces (precised documentation)

> Provides better diagnostics

> Simplify usage of SFINAE / enable_if
>
> - Introspection by design / Optional interfaces

> Can be emulated in C++14/C++17 (So far!)
>
> - `variable templates` / `constexpr` / `constexpr if`

> C++20 is just the beginning
>
> - `syntax improvements` / `requirements improvements`
> - `virtual concepts` / `metaclasses` / `static reflection`

Questions?

C++20 draft	http://eel.is/c++draft/temp.constr
Concepts	https://wg21.link/P0734R0
Virtual Concepts	https://github.com/andyprowl/virtual-concepts/blob/master/draft/Dynamic Generic Programming with Virtual Concepts.pdf