Back To Basics
Name Lookup and Overload Resolution

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Workshopy Style

Workshopy Style

- Provide rationale
- Facilitate discussion
  - force the audience to think
  - not just a lecture
- Describe
  - pitfalls
  - corner cases
- Provide recommendations
- ~~Lot's of coding~~

https://ahaslides.com/NLOR

Name Lookup and Overload Resolution

Name Lookup and Overload Resolution are among the most complex and the most expensive at compile time features of the C++ language.

Why to allow more than one function with the same name?

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>
> *-- Titus Winters*

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TERSE, ROBUST, AND FAST INTERFACES

```
void print(const X& x);
void print(const Y& y);
```

```
void print_X(const X& x);
void print_Y(const Y& y);
```

Why to allow more than one function with the same name?

Overload Set is the "atom" of C++ API design.

-- Titus Winters

GENERIC PROGRAMMING

- No dynamic polymorphism needed to have a single interface entry point

```
void print(const auto& v);
```

```
void print(const printable& v);
```

Why to allow more than one function with the same name?

> Overload Set is the "atom" of C++ API design.
>
> *-- Titus Winters*

FRIENDLY SYNTAX WITH OPERATORS OVERLOADING

```
MyInt a{1}, b{2};
auto res = a + b;
```

```
MyInt a{1}, b{2};
auto res = add(a, b);
```

Why to allow more than one function with the same name?

> Overload Set is the "atom" of C++ API design.
>
> *-- Titus Winters*

CUSTOMIZATION POINTS

```
struct X { int value; };
std::ostream& operator<<(std::ostream& os, const X& x);
```

```
X x;
std::cout << x << "\n";
```

Ad hoc polymorphism

Function has different implementations depending on a *limited range of individually specified types and combinations*.

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void print(const Y& y);
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```
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void print(const Y& y);
```

In the C++ language multiple functions and function templates **may share the same name**. Each of them **must have a different set of parameters or template parameter constraints**, and may provide different return types. The compiler will **select the best matching function at compile-time**.

Overload sets

C.162: Overload operations that are roughly equivalent.

-- C++ Core Guidelines

GOOD

```
void print(int a);
void print(int a, int base);
void print(const string&);
```

BAD

```
void print_int(int a);
void print_based(int a, int base);
void print_string(const string&);
```

Overload sets

C.163: Overload only for operations that are roughly equivalent.

-- C++ Core Guidelines

GOOD

```
void open_gate(Gate& g);    // remove obstacle from garage exit lane
void fopen(const char* name, const char* mode);    // open file
```

BAD

```
void open(Gate& g);    // remove obstacle from garage exit lane
void open(const char* name, const char* mode ="r");    // open file
```

Overload sets

Use overloaded functions (including constructors) only if a reader looking at a call site **can get a good idea of what is happening without having to first figure out exactly which overload is being called**.

-- Google C++ Style

Properties of a good overload set

- Correctness can be judged at the call site **without knowing which overload is picked**
- A single comment can **describe the full set**
- Each element of the set is **doing "the same thing"**

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- A single comment can **describe the full set**
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EXAMPLE

```
void vector<T>::push_back(const T&);
void vector<T>::push_back(T&&);
```

```
v.push_back("hello"s);
v.push_back(std::move(world));
```

- If we remove the second overload, the same behavior but not performance

A process of calling a function in C++

A process of calling a function in C++

1 Name Lookup

A process of calling a function in C++

1. Name Lookup
2. Template Argument Deduction

A process of calling a function in C++

1. Name Lookup
2. Template Argument Deduction
3. Overload Resolution

A process of calling a function in C++

1. Name Lookup
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4. Member Access Rules

A process of calling a function in C++

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5. Function Template Specializations

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A process of calling a function in C++

1. Name Lookup
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7. Deleting Functions

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1. Name Lookup
2. Template Argument Deduction
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Name Lookup

Name lookup is the procedure by which a name, when encountered in a program, is associated with the declaration that introduced it.

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Name lookup is the procedure by which a name, when encountered in a program, is associated with the declaration that introduced it.

The result of the function name lookup process is a set of candidate functions.

Name Lookup

QUALIFIED NAME LOOKUP

UNQUALIFIED NAME LOOKUP

Name Lookup

QUALIFIED NAME LOOKUP

- Name that appears *on the right hand side* of the scope resolution operator `::`

UNQUALIFIED NAME LOOKUP

- Name that does *not appear to the right* of a scope resolution operator `::`

Name Lookup

QUALIFIED NAME LOOKUP

- Name that appears *on the right hand side* of the scope resolution operator `::`

UNQUALIFIED NAME LOOKUP

- Name that does *not appear to the right* of a scope resolution operator `::`

Before a qualified name lookup can be performed for the name on the right hand side of `::`, lookup must be completed for the name on its left hand side.

Name Lookup

QUALIFIED NAME LOOKUP

- Name that appears *on the right hand side* of the scope resolution operator **::**

UNQUALIFIED NAME LOOKUP

- Name that does *not appear to the right* of a scope resolution operator **::**

```cpp
#include <iostream>

int main()
{
  struct std {};
//std::cout << "fail\n"; // Error: unqualified lookup for 'std' finds the struct
  ::std::cout << "ok\n"; // OK: ::std finds the namespace std
}
```

- **cout** above is always looked up in a qualified way

Qualified Name Lookup

- A qualified name **may refer to**
  - class member
  - namespace member
  - enumerator

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If there is nothing on the left hand side of the `::`, the lookup considers only declarations made in the global namespace scope or introduced into the global namespace by a `using` declaration.

AhaSlides: Which function is selected?

```cpp
namespace my_namespace {
void func(const std::string&);

namespace internal {
void func(int);

namespace deep {
void test()
{
  std::string s("hello");
  func(s);
}

} // namespace deep
} // namespace internal
} // namespace my_namespace
```

AhaSlides: Which function is selected?

```
namespace my_namespace {
void func(const std::string&);

namespace internal {
void func(int);

namespace deep {
void test()
{
  std::string s("hello");
  func(s);
}

} // namespace deep
} // namespace internal
} // namespace my_namespace
```

```
error: cannot convert 'std::string' to 'int' for argument '1' to
       'void my_namespace::internal::func(int)'
```

Unqualified Name Lookup

Unqualified name lookup examines the scopes, **until it finds at least one declaration of any kind** (does not have to be a function) **with a matching name**, at which time **scopes traversing stops** and no further scopes are examined.

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Unqualified name lookup examines the scopes, **until it finds at least one declaration of any kind** (does not have to be a function) **with a matching name**, at which time **scopes traversing stops** and no further scopes are examined.

Even if there are other functions with the same name in the outer scopes, they are hidden from the lookup process.

Nested namespaces: Pitfalls

```
namespace my_namespace {
void func(double);

namespace internal {

namespace deep {
void test()
{
  func(3.14);
}

} // namespace deep
} // namespace internal
} // namespace my_namespace
```

Nested namespaces: Pitfalls

```
namespace my_namespace {
void func(double);

namespace internal {
void func(int);

namespace deep {
void test()
{
  func(3.14);
}

} // namespace deep
} // namespace internal
} // namespace my_namespace
```

Program still compiles fine but may not work as expected.

Recommendation: Nested namespaces

To prevent unexpected lookup problems try to keep your namespaces flat and shallow wherever possible.

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To prevent unexpected lookup problems try to keep your namespaces flat and shallow wherever possible.

This is C++, not Java ;-)

Nested overloads

The same scoping-based lookup rules apply to overloads in a class hierarchy.

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The same scoping-based lookup rules apply to overloads in a class hierarchy.

```
struct Base {
  void func(double);
};

struct Derived : Base {
  void func(int);
};
```

```
Derived d;
d.func(3.14);
```

Name Lookup from regular functions

```
void func(int);
void func(double);

namespace N1 {

void test()
{
  std::string s("hello");
  func(s);
}

void func(const std::string&);

}
```

```
N1::test();
```

Name Lookup from regular functions

```
void func(int);
void func(double);

namespace N1 {

void test()
{
  std::string s("hello");
  func(s);
}

void func(const std::string&);

}
```

```
N1::test();
```

```
error: no matching function for call to 'func(std::string&)'
note: candidate: 'void func(int)'
note:   no known conversion for argument 1 from 'std::string' to 'int'
note: candidate: 'void func(double)'
note:   no known conversion for argument 1 from 'std::string' to 'double'
```

Name Lookup from regular functions

```cpp
void func(int);
void func(double);

namespace N1 {

void test()
{
  std::string s("hello");
  func(s);
}

void func(const std::string&);

}
```

```cpp
N1::test();
```

Name lookup in regular function considers only function candidates *visible from its definition context*.

Argument-dependent lookup (ADL, Koenig lookup)

```
namespace N2 {

struct X {};
void func(const X&);

}

namespace N1 {

void test(N2::X x) { func(x); }

}
```

```
N2::X x{};
N2::func(x);
N1::test(x);
```

Argument-dependent lookup (ADL, Koenig lookup)

```
namespace N2 {

struct X {};
void func(const X&);

}

namespace N1 {

void test(N2::X x) { func(x); }

}
```

```
N2::X x{};
N2::func(x);
N1::test(x);
```

ADL is the set of rules for looking up the unqualified function names in function-call expressions. These function names are *looked up in the namespaces of their arguments*.

AhaSlides: Tell me about the code?

```cpp
namespace a {
  using my_array = std::vector<int>;

  void print(const my_array& array)
  {
    // ...
  }
}

void foo(const a::my_array& array)
{
  print(array);
}
```

```cpp
namespace a {
  struct my_array { std::vector<int> data; };

  void print(const my_array& array)
  {
    // ...
  }
}

void foo(const a::my_array& array)
{
  print(array);
}
```

AhaSlides: Tell me about the code?

```cpp
namespace a {
  using my_array = std::vector<int>;

  void print(const my_array& array)
  {
    // ...
  }
}

void foo(const a::my_array& array)
{
  print(array);
}
```

```
error: 'print' was not declared in this scope
```

```cpp
namespace a {
  struct my_array { std::vector<int> data; };

  void print(const my_array& array)
  {
    // ...
  }
}

void foo(const a::my_array& array)
{
  print(array);
}
```

```
Compiler returned: 0
```

AhaSlides: Tell me about the code?

```cpp
namespace a {
  using my_array = std::vector<int>;

  void print(const my_array& array)
  {
    // ...
  }
}

void foo(const a::my_array& array)
{
  print(array);
}
```

```
error: 'print' was not declared in this scope
```

```cpp
namespace a {
  struct my_array { std::vector<int> data; };

  void print(const my_array& array)
  {
    // ...
  }
}

void foo(const a::my_array& array)
{
  print(array);
}
```

```
Compiler returned: 0
```

The aliases are fully resolved and expanded to their source types before the list of namespaces to ADL search are chosen.

AhaSlides: Tell me about the code?

```cpp
namespace N2 {

struct X {
  friend void func(const X&) { /* ... */ }
};

}

namespace N1 {

void test(N2::X x) { func(x); }  // OK

}
```

```cpp
N2::X x{};
N2::func(x);    // ???
N1::test(x);    // ???
```

AhaSlides: Tell me about the code?

```cpp
namespace N2 {

struct X {
  friend void func(const X&) { /* ... */ }
};

}

namespace N1 {

void test(N2::X x) { func(x); }  // OK

}
```

```cpp
N2::X x{};
N2::func(x);   // ???
N1::test(x);   // ???
```

```
error: 'func' is not a member of 'N2'
```

Hidden Friends

Friend function *publicly declared and defined inside* of a class and *taking this class type as an argument* is called a **Hidden Friend**.

```
struct X {
  friend void func(const X&) { /* ... */ }
};
```

Hidden Friends

Friend function *publicly declared and defined inside* of a class and *taking this class type as an argument* is called a **Hidden Friend**.

```
struct X {
  friend void func(const X&) { /* ... */ }
};
```

Such function **can be found only through the ADL**.

Recommendation: Hidden Friends

Prefer Hidden Friend functions rather than global non-member functions **to overload operators or implement other common customization points**. *Do it even when access to the private class members is not required* in the function's definition.

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Prefer Hidden Friend functions rather than global non-member functions **to overload operators or implement other common customization points**. *Do it even when access to the private class members is not required* in the function's definition.

`friend` functions are not a part of the candidate set for arguments of other types which means they make the name lookup and overload resolution process faster.

Name Lookup from function templates

```cpp
namespace N1 {

void test(auto v)  // look Ma, a template!
{
  func(v);     // OK
  func(123);   // Error
}

void func(int);   // not found

}

namespace N2 {

struct X {};
void func(const X&);   // found

}
```

```cpp
N2::X x{};
N1::test(x);
```

```
error: there are no arguments to 'func' that depend on a template parameter,
       so a declaration of 'func' must be available
```

Name Lookup from function templates

```
namespace N1 {

void test(auto v)
{
  func(v);     // Error
}

}

namespace N2 {

struct X {};

}
```

```
void func(const N2::X&);  // not found

N2::X x{};
N1::test(x);
```

```
error: 'func' was not declared in this scope, and no declarations were found by
       argument-dependent lookup at the point of instantiation
```

Dependent names

- Inside the definition of a template, the *meaning of some constructs may differ* from one instantiation to another

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- Inside the definition of a template, the *meaning of some constructs may differ* from one instantiation to another
- **Types and expressions may depend on types and values of template parameters**

```
template<typename T>
struct X : B<T>              // B<T> is dependent on T
{
  typename T::A* pa;         // T::A is dependent on T
  void f(B<T>* pb)
  {
    static int i = B<T>::i; // B<T>::i is dependent on T
    pb->j++;                 // pb->j is dependent on T
  }
};
```

Dependent names

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template<typename T>
struct X : B<T>              // B<T> is dependent on T
{
  typename T::A* pa;         // T::A is dependent on T
  void f(B<T>* pb)
  {
    static int i = B<T>::i; // B<T>::i is dependent on T
    pb->j++;                 // pb->j is dependent on T
  }
};
```

- *Name lookup* and *binding are different* for dependent names and non-dependent names

Dependent names: Binding

- *Non-dependent* names are looked up and bound *at the point of template definition*

Dependent names: Binding

- *Non-dependent* names are looked up and bound *at the point of template definition*
- This binding *holds even if* at the point of template instantiation *there is a better match*

```
void g(double);

template<class T>
struct S {
  void f() const { g(1); } // "g" is a non-dependent name, bound now
};

void g(int);
```

```
g(1);        // calls g(int)
S<int> s;
s.f();       // calls g(double)
```

Dependent names: Binding

- *Non-dependent* names are looked up and bound *at the point of template definition*
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void g(double);

template<class T>
struct S {
  void f() const { g(1); } // "g" is a non-dependent name, bound now
};

void g(int);
```

```
g(1);        // calls g(int)
S<int> s;
s.f();       // calls g(double)
```

- Binding of *dependent names* is postponed *until lookup takes place*

Dependent names: Lookup

- The lookup of a dependent name used in a template is *postponed until the template arguments are known*

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Dependent names: Lookup

- The lookup of a dependent name used in a template is *postponed until the template arguments are known*
- **non-ADL lookup** examines function declarations with external linkage that are *visible from the template definition context*
- **ADL** examines function declarations with external linkage that are *visible from both the template definition* context and the *template instantiation* context

Dependent names: Lookup

- The lookup of a dependent name used in a template is *postponed until the template arguments are known*
- **non-ADL lookup** examines function declarations with external linkage that are *visible from the template definition context*
- **ADL** examines function declarations with external linkage that are *visible from both the template definition* context and the *template instantiation* context
- Adding a new function declaration *after template definition does not make it visible, except via ADL*

Generic frameworks with customization points

convert.h

```
template<typename T>
void convert(std::string_view str, T& out)
{
  // default implementation
}

template<typename T>
T from_string(std::string_view str)
{
  T t;
  convert(str, t);
  return t;
}
```

Generic frameworks with customization points

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template<typename T>
T from_string(std::string_view str)
{
  T t;
  convert(str, t);
  return t;
}
```

price.h

```
struct price { int value; };

void convert(std::string_view str, price& p)
{
  convert(str, p.value);
}
```

Generic frameworks with customization points

convert.h

```
template<typename T>
void convert(std::string_view str, T& out)
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  // default implementation
}

template<typename T>
T from_string(std::string_view str)
{
  T t;
  convert(str, t);
  return t;
}
```

price.h

```
struct price { int value; };

void convert(std::string_view str, price& p)
{
  convert(str, p.value);
}
```

main.cpp

```
#include "convert.h"
#include "price.h"

price p = from_string<price>("123");
```

Generic frameworks with customization points

convert.h

```cpp
template<typename T>
void convert(std::string_view str, T& out)
{
  // default implementation
}

template<typename T>
T from_string(std::string_view str)
{
  T t;
  convert(str, t);
  return t;
}
```

price.h

```cpp
struct price { int value; };

void convert(std::string_view str, price& p)
{
  convert(str, p.value);
}
```

main.cpp

```cpp
#include "convert.h"
#include "price.h"

price p = from_string<price>("123");
```

All customization points benefit from this property.

AhaSlides: swap() the type

```
template<typename T>
struct wrapper {
  T data_;
};

template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  // ???
}
```

```
wrapper<std::string> s1, s2;
swap(s1, s2);
```

Which of the following will work correctly?

- `swap(lhs.data_, rhs.data_);`
- `std::swap(lhs.data_, rhs.data_);`
- `std::ranges::swap(lhs.data_, rhs.data_);`

Answer: swap() the type

```
template<typename T>
struct wrapper {
  T data_;
};

template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  // ???
}
```

```
wrapper<std::string> s1, s2;
swap(s1, s2);
```

All work as expected

AhaSlides: swap() the type

```
template<typename T>
struct wrapper {
  T data_;
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template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  // ???
}
```

```
struct X {};

void swap(X&, X&)
{ std::cout << "my swap\n"; }
```

```
wrapper<std::string> s1, s2;
swap(s1, s2);

wrapper<X> x1, x2;
swap(x1, x2);
```

Which of the following will work correctly?

- `swap(lhs.data_, rhs.data_);`
- `std::swap(lhs.data_, rhs.data_);`
- `std::ranges::swap(lhs.data_, rhs.data_);`

Answer: swap() the type

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template<typename T>
struct wrapper {
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template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  // ???
}
```

```
struct X {};

void swap(X&, X&)
{ std::cout << "my swap\n"; }
```

```
wrapper<std::string> s1, s2;
swap(s1, s2);

wrapper<X> x1, x2;
swap(x1, x2);
```

- **`std::swap()`** compiles but does not work as expected
- **`swap()`** and **`std::ranges::swap()`** work correctly

AhaSlides: swap() the type

```
template<typename T>
struct wrapper {
  T data_;
};

template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  // ???
}
```

```
struct X {};

void swap(X&, X&)
{ std::cout << "my swap\n"; }
```

```
wrapper<std::string> s1, s2;
swap(s1, s2);

wrapper<X> x1, x2;
swap(x1, x2);

wrapper<int> i1, i2;
swap(i1, i2);
```

Which of the following will work correctly?

- `swap(lhs.data_, rhs.data_);`
- `std::swap(lhs.data_, rhs.data_);`
- `std::ranges::swap(lhs.data_, rhs.data_);`

Answer: swap() the type

```
template<typename T>
struct wrapper {
  T data_;
};

template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  // ???
}
```

```
struct X {};

void swap(X&, X&)
{ std::cout << "my swap\n"; }
```

```
wrapper<std::string> s1, s2;
swap(s1, s2);

wrapper<X> x1, x2;
swap(x1, x2);

wrapper<int> i1, i2;
swap(i1, i2);
```

- **swap()** does not compile
- **std::swap()** does not work (but compiles)
- **std::ranges::swap()** works as expected

using declarations

```cpp
template<typename T>
struct wrapper {
  T data_;
};

template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  using std::swap;
  swap(lhs.data_, rhs.data_);
}
```

```cpp
struct X {};

void swap(X&, X&)
{ std::cout << "my swap\n"; }
```

```cpp
wrapper<std::string> s1, s2;
swap(s1, s2);

wrapper<X> x1, x2;
swap(x1, x2);

wrapper<int> i1, i2;
swap(i1, i2);
```

Using declarations can be used to introduce namespace members into other namespaces and block scopes.

Customization Point Object (CPO, Niebloid)

```
template<typename T>
struct wrapper {
  T data_;
};

template<typename T>
void swap(wrapper<T>& lhs,
          wrapper<T>& rhs)
  noexcept(std::is_nothrow_swappable_v<T>)
{
  std::ranges::swap(lhs.data_, rhs.data_);
}
```

```
struct X {};

void swap(X&, X&)
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```
wrapper<std::string> s1, s2;
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```

- Customization interface *entry point can not be found through ADL*
- Customization point *function found only via ADL*

Customization Point Object (CPO, Niebloid)

```
namespace std::ranges {
  namespace swap_impl {









    struct fn {










    };
  }

  inline constexpr swap_impl::fn swap;
}
```

Customization Point Object (CPO, Niebloid)

```
namespace std::ranges {
  namespace swap_impl {



    template<typename T>
    inline constexpr bool has_customization =
      requires(T& t) {
        swap(t, t);  // uses ADL
      };

    struct fn {










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    struct fn {
      template<typename T>
      constexpr void operator()(T& lhs, T& rhs) const
      {
        if constexpr(has_customization<T>)
          swap(lhs, rhs);  // uses ADL
        else {
          // default implementation
          // ...
        }
      }
    };
  }

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Customization Point Object (CPO, Niebloid)

```
namespace std::ranges {
  namespace swap_impl {
    // non-ADL lookup block (poison pill)
    void swap(); // undefined

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        }
      }
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  }

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}
```

```
struct X {};

void swap(X&, X&)
{ std::cout << "my swap\n"; }
```

```
std::string s1, s2;
std::ranges::swap(s1, s2);

X x1, x2;
std::ranges::swap(x1, x2);

int i1{1}, i2{2};
std::ranges::swap(i1, i2);
```

AhaSlides: Which is being called?

```
template<class T> void f(T);     // #1
template<>        void f(int*); // #2
template<class T> void f(T*);   // #3

f(new int{1});
```

Overloads vs explicit function template specializations

```
template<class T> void f(T);     // #1: overload for all types
template<>        void f(int*); // #2: specialization of #1 for pointers to int
template<class T> void f(T*);   // #3: overload for all pointer types

f(new int{1});   // calls #3, even though specialization of #1 would be a perfect match
```

- Only **non-template** and **primary template** overloads participate in *overload resolution*
- The **specializations** are not overloads and *are not considered*
- Only *after the overload resolution selects* the best-matching **primary function template**, its ***specializations*** *are examined* to see if one is a better match

A process of calling a function in C++

1. Name Lookup
2. Template Argument Deduction
3. **Overload Resolution**
4. Member Access Rules
5. Function Template Specializations
6. Virtual Dispatch
7. Deleting Functions

Overload Resolution

A process of **selecting the most appropriate overload** at compile-time based on the passed argument types (not actual values).

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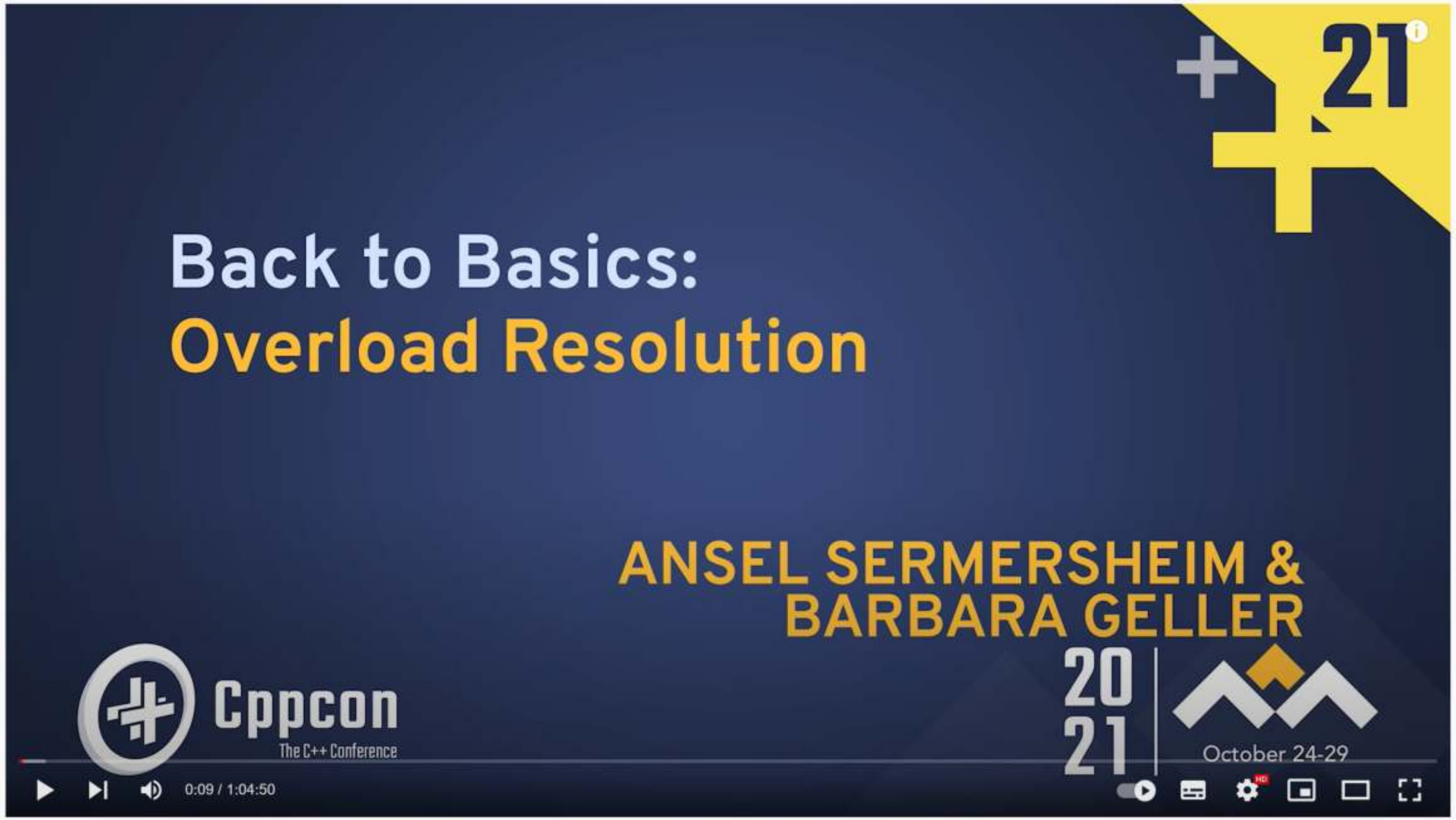
The input for a process is a candidate set of function overloads found by the Name Lookup step.

Back To Basics: Overload Resolution - CppCon 2021



CppCon 2021 - Back To Basics

Back To Basics: Overload Resolution - CppCon 2021

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  - candidates have *less parameters*
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  - candidate's associated *constraints are not satisfied*
  - passed *arguments are not implicitly convertible* to function parameters' types
- **Ranks** the remaining candidates via pair-wise comparisons
- If **exactly one** viable function **is better than all others**, this **function is called**
  - otherwise, **compilation fails**

Ranking

For each pair of viable function **F1** and **F2**, the **implicit conversion sequences from the i-th argument to i-th parameter are ranked** to determine which one is better.

Conversion ranks

RANK	CATEGORY	CONVERSIONS
1	exact match	no conversion required trivial conversions
2	promotions	integral or floating-point promotion integral or floating-point promotion + trivial conversions
3	conversions	standard conversion standard conversion + trivial conversions
4	user-defined	user-defined conversion user-defined conversion + trivial conversions user-defined conversion + standard conversion
5	ellipsis	... C-style function argument

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- ...

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- Less cv-qualified reference or pointer wins
- ...

If no tie breakers can be applied in such a situation, the call is ambiguous.

Examples: Standard Conversions

```
void foo(const int&);  // #1
void foo(const int&&); // #2

int i = 123;
foo(i);    // 'lvalue int -> const int&' is the only valid conversion
foo(123); // 'rvalue int -> const int&&' better than 'rvalue int -> const int&'
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```

```cpp
void foo(const int&); // #1
void foo(int);        // #2

int i = 123;
foo(i);   // error: call of overloaded 'foo(int&)' is ambiguous (rank Exact Match)
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foo(i);   // error: call of overloaded 'foo(int&)' is ambiguous (rank Exact Match)
foo(123); // error: call of overloaded 'foo(int)' is ambiguous (rank Exact Match)
```

```
int f(const int*); // '&i -> const int*'
int f(int*);       // '&i -> int*'

int i;
int j = f(&i); //  calls f(int*)
```

Example: User-defined Conversions

```cpp
struct A {
  operator short();
};

int f(int);   // 'A -> short', followed by 'short -> int' (rank Promotion)
int f(float); // 'A -> short', followed by 'short -> float' (rank Conversion)

A a;
int i = f(a); // calls f(int)
```

Functions vs function templates

If a function and template function overloads are deemed equal, a *non-template function will be selected*.

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If a function and template function overloads are deemed equal, a *non-template function will be selected*.

```
template<typename T>
T from_string(std::string_view str);

struct converter; {
  std::string_view str;

  template<typename To>
  operator To() const { return from_string<To>(str); }
};

converter from_string(std::string_view str) { return converter{str}; }
```

Function templates vs function templates

If both candidates are template specializations, a *more specialized one* according to the partial ordering rules for template specializations *wins*.

Constrained no-template functions

If both are non-template functions with the same parameter-type-lists, a *more constrained one* according to the partial ordering of constraints *wins*.

Constrained no-template functions

```
template<auto V>
struct X {
  using type = decltype(V);

  static void foo()
  { std::cout << "Other\n"; }

  static void foo()
    requires std::integral<type>
  { std::cout << "Integral\n"; }

  static void foo()
    requires std::signed_integral<type>
  { std::cout << "Signed Integral\n"; }

  static void foo()
    requires std::floating_point<type>
  { std::cout << "Floating-point\n"; }
};
```

```
X<123>::foo();          // Signed Integral
X<123U>::foo();         // Integral
X<3.14>::foo();         // Floating-point
X<std::kilo{}>::foo(); // Other
```

Ranking for multiple arguments

In order for F1 to be determined a better function than F2 the implicit *conversions for all arguments of F1 must be not worse* than the corresponding conversions of F2 arguments and *at least conversion for one argument of F1 must be considered better*.

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```
void foo(int, double, int);     // #1
void foo(double, int, double); // #2
```

```
foo(42, 3.14, 42U);       // (R1, R1, R1) vs (R3, R3, R3) -> calls #1
foo(3.14, 42U, 12);       // (R3, R3, R1) vs (R1, R3, R3) -> ambiguous
foo(42, short{14}, 42); // (R1, R3, R1) vs (R3, R2, R3) -> ambiguous
```

Recommendation: Resolving ambiguity

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1. Use `explicit` constructors and conversion operators by default
2. Use constraints on function templates and regular functions whenever possible
3. Explicitly convert function argument to required type on a function call site

Recommendation: Overload Resolution

Keep your overloads simple and easy. Do not make your life's and computer's work harder ;-)

Bonus: Member Access Rules Check

Member access is checked on the best candidate only after the Overload Resolution is done. If it requires the inaccessible member access, the compilation fails.

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Member access is checked on the best candidate only after the Overload Resolution is done. If it requires the inaccessible member access, the compilation fails.

```
struct X {
  void foo(int) { std::cout << "int\n"; }
private:
  void foo(double) { std::cout << "double\n"; }
};
```

```
X x;
x.foo(3.14);  // error: 'void X::foo(double)' is private within this context
```

CAUTION
Programming
is addictive
(and too much fun)