HIGH-LEVEL PROGRAMMING 2

Function Templates: Overloading and Specialization
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Function Overloading (1/3)

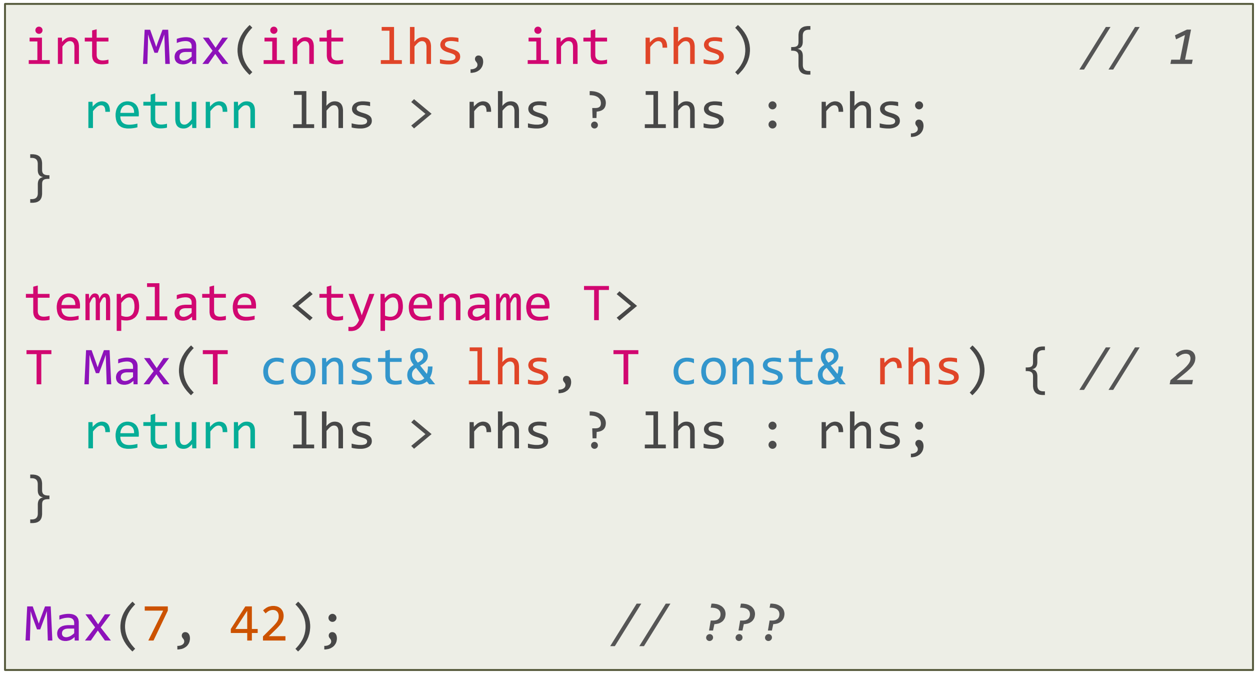
- C++ lets us overload nontemplate functions, yet makes sure the right one is called:

```
int foo(int);       // 1
double foo(double); // 2

int i;
double d;
foo(i);     // exact match with 1
foo(d);     // exact match with 2
foo('a');   // ???
foo(i+d);   // ???
foo(10.1f); // ???
foo(10.1L); // ???
foo(10UL);  // ???
```

Function Overloading (2/3)

- □ Nontemplate function can coexist with function template that has same name and can be instantiated with same type



```cpp
int Max(int lhs, int rhs) {         // 1
  return lhs > rhs ? lhs : rhs;
}

template <typename T>
T Max(T const& lhs, T const& rhs) { // 2
  return lhs > rhs ? lhs : rhs;
}

Max(7, 42);             // ???
```

Function Overloading (3/3)

- All other factors being equal, overload resolution process prefers nontemplate over one generated from template

```
int Max(int lhs, int rhs) {         // 1
  return lhs > rhs ? lhs : rhs;
}

template <typename T>
T Max(T const& lhs, T const& rhs) { // 2
  return lhs > rhs ? lhs : rhs;
}
```

```
Max(7, 42);             // ???
Max(7.0, 42.0);         // ???
Max('a', 'b');          // ???
Max<double>(7, 42);     // ???
Max<>(7, 42);           // ???
Max('a', 42.7);         // ???
```

This syntax makes it possible to specify explicity an *empty template argument list*. This syntax indicates that only templates may resolve a call, but *template parameters must be deduced from call arguments*!!!

Why Overload Function Templates? (1/3)

- Function templates can themselves be overloaded
  - Performance is common reason to overload
  - We might want to overload a template to work with certain objects that don’t conform to normal interface expected by generic template

Why Overload Function Templates? (2/3)

- □ <algorithm> defines function template std::swap to exchange two values
- □ "stack.hpp" defines member function to exchange with another stack

```
namespace std {
  template <typename T>
  void swap(T &lhs, T &rhs) {
    T tmp{lhs};
    lhs = rhs;
    rhs = tmp;
  }
}
```

```
template <typename T>
class Stack {
public:
  // public interface ....
  void swap(Stack&);
private:
  size_t max_sz;
  size_t top_idx;
  T      *v;
};
```

Why Overload Function Templates? (3/3)?

- □ Using `std::swap` to exchange two values of type `Stack<T>` is expensive!!!
- □ Standard library requires every container to overload `std::swap`

```
namespace std {
  template <typename T>
  void swap(T &lhs, T &rhs) {
    T tmp{lhs};
    lhs = rhs;
    rhs = tmp;
  }
}
```

```
template <typename T>
class Stack {
public:
  void swap(Stack&);
private:
  size_t max_sz;
  size_t top_idx;
  T      *v;
};

template <typename T>
void swap(Stack<T> &a, Stack<T> &b) {
    a.swap(b);
}
```

Overloading Function Templates

```
// 1: maximum of two values of any type
template <typename T>
T Max(T lhs, T rhs) {
  return lhs > rhs ? lhs : rhs;
}

// 2: maximum of two pointers
template <typename T>
T* Max(T *lhs, T *rhs) {
  return *lhs>*rhs ? lhs : rhs;
}

// 3: maximum of two cstrings
char const* Max(char const *lhs, char const *rhs) {
  return std::strcmp(lhs, rhs) > 0 ? lhs : rhs;
}

// 4: maximum of three values of any type
template <typename T>
T Max(T a, T b, T c) {
  return Max(Max(a, b), c);
}
```

```
int i1{7}, i2{42};
int *p1{&i1}, *p2{&i2};
std::string s1{"hey"}, s2{"you"};
char const *c1{"you"}, *c2{"hey"};
char const *c3{"hey you"};

Max(i1, i2);      // ???
Max(s1, s2);      // ???
Max(p1, p2);      // ???
Max(c1, c2);      // ???
Max(c1, c2, c3); // ???
```

Overloading Function Templates (2/9)

- Note that in all overloads of `Max`, we pass arguments by value
- In general, good idea not to change more than necessary when overloading function templates
  - You should limit changes to number of parameters or to specifying template parameters explicitly
- Otherwise, unexpected effects may happen

Overloading Function Templates (3/9)

```cpp
// max of two values
template <typename T>
T const& Max(T const& lhs, T const& rhs) {
  return lhs > rhs ? lhs : rhs;
}

// incorrect version: max of two C-strings
char const* Max(char const *lhs, char const *rhs) {
  return std::strcmp(lhs, rhs) > 0 ? lhs : rhs;
}

// max of three values
template <typename T>
T const& Max(T const& a, T const& b , T const& c) {
  return Max(Max(a, b), c);
}
```

```cpp
char const *c1{"you"};
char const *c2{"hey"};
char const *c3{"hey you"};

Max(c1, c2, c3); // error!!! ???
```

Overloading Function Templates (4/9)

```
char const *c1{"you"};
char const *c2{"hey"};
char const *c3{"hey you"};

Max(c1, c2, c3); // ok: ???
```

```
// max of two values
template <typename T>
T const& Max(T const& lhs, T const& rhs) {
  return lhs > rhs ? lhs : rhs;
}

// correct version: max of two C-strings
char const* const&
Max(char const* const& lhs, char const* const& rhs) {
  return std::strcmp(lhs, rhs) > 0 ? lhs : rhs;
}

// max of three values
template <typename T>
T const& Max(T const& a, T const& b , T const& c) {
  return Max(Max(a, b), c);
}
```

Overloading Function Templates (5/9)

```
// 1: max of two values of any type
template <typename T>
T Max(T lhs, T rhs) {
  return lhs > rhs ? lhs : rhs;
}

// 2: max of three values of any type
template <typename T>
T Max(T a, T b, T c) {
  return Max(Max(a, b), c);
}

// 3: max of two int values
int Max(int lhs, int rhs) {
  return lhs > rhs ? lhs : rhs;
}
```

Ensure all overloaded versions of a function are declared before the function is called!!!

```
int i1{47}, i2{11}, i3{33};

// problem when Max is called!!!
Max(i1, i2, i3); // ???
```

Overloading Function Templates (6/9)

```cpp
// 1: max of two values of any type
template <typename T>
T Max(T lhs, T rhs) {
  return lhs > rhs ? lhs : rhs;
}

// 2: max of three values of any type
template <typename T>
T Max(T a, T b, T c) {
  return Max(Max(a, b), c);
}

// 3: max of two int values
int Max(int lhs, int rhs) {
  return lhs > rhs ? lhs : rhs;
}
```

Notice nontemplate function overload is now declared before Max of 3 values so it is visible to Max of 3 values!!!

```cpp
int i1{47}, i2{11}, i3{33};

Max(i1, i2, i3); // ???
```

Overloading Function Templates (7/9)

- Two function templates with same name can coexist even though they may be instantiated so that both have identical parameter types

Overloading Function Templates (8/9)

```
template <typename T>
int f(T) {
  return 1;
}

template <typename T>
int f(T*) {
  return 2;
}

int x{10}, *px{&x};

f<int*>(px); // calls f<T>(T)  == f(int*)
f<int>(px);  // calls f<T>(T*) == f(int*)
```

After substituting given template argument lists (`<int*>` and `<int>`), overload resolution ends up picking the right function to call

Two function templates with same name can coexist even though they may be instantiated so that both have identical parameter types

Overloading Function Templates (9/9)

```
// 1
template <typename T>
int f(T) {
  return 1;
}

// 2
template <typename T>
int f(T*) {
  return 2;
}

int x{10}, *px{&x};

f(*px); // calls f<T>(T)
f(px);  // can call either f<int*>(int*) or f<int>(int*)
        // special overloading rules will pick f<int>(int*)
        // because it is more specialized!!!
```

Even without explicit template arguments, template argument deduction and special overloading rules will select right function to call!!!

For expression `f(px)`, compiler can instantiate either function template 1 or 2.
However, compiler will instantiate function template 2 since 2's instantiation is more *specialized* than 1 [because 2 takes fewer types than 1]!!!

Function Template Specialization (1/3)

```cpp
// 1: max of two values of any type
template <typename T>
const T& Max(T const& lhs, T const& rhs) {
  return lhs > rhs ? lhs : rhs;
}

// 2: max of two pointers of any type
template <typename T>
T* const& Max(T* const& lhs, T* const& rhs) {
  return *lhs > *rhs ? lhs : rhs;
}

int i1{1}, i2{2}, *pi1{&i1}, *pi2{&i2};
char const *pc1 = "San Jose", *pc2 = "Santiago";
Max(1, 2);     // ok: calls 1
Max(pi1, pi2); // ok: calls 2
Max(pc1, pc2); // error!!! calls 2
```

Function Template Specialization (2/3)

```cpp
// base template 1: max of two values of any type
template <typename T>
const T& Max(T const& lhs, T const& rhs) {
  return lhs > rhs ? lhs : rhs;
}
// base template 2: max of two pointers of any type
template <typename T>
T* const& Max(T* const& lhs, T* const& rhs) {
  return *lhs > *rhs ? lhs : rhs;
}
// 3: special version of 2 to handle pointers to char arrays
template <>
const char* const& Max(char const* const& lhs, char const* const& rhs) {
  return std::strcmp(lhs, rhs) > 0 ? lhs : rhs;
}

char const *pc1 = "San Jose", *pc2 = "Santiago";
Max(pc1, pc2); // ok: calls 3
```

Function Template Specialization (3/3)

- Specializations instantiate a base template, they don’t overload it
- As a result, specializations don’t participate in function matching

Function Templates: Simplified Overload Rules (1/2)

- Nontemplate functions are first-class citizens
  - Nontemplate function that matches parameter types as well as any function template will be selected over otherwise-just-as-good function template
- If there are no first-class citizens to choose from that are at least as good, then function base templates as second-class citizens get consulted next based on which matches best and is “most specialized” according to fairly arcane rules:
  - If it's clear that there's one "most specialized" function base template, that one gets used; if that base template happens to be specialized for the types being used, the specialization will get used, otherwise base template instantiated with correct types will be used
  - Else if there's tie for "most specialized" function base template, call is ambiguous because compiler can't decide which is a better match; programmer will have to do something to qualify the call and say which one is wanted
  - Else if there’s no function base template that can be made to match, call is bad; programmer will have to fix the code

Function Templates: Simplified Overload Rules (2/2)

```
template <typename T> void f(T);              // a
template <typename T> void f(int, T, double); // b
template <typename T> void f(T*);             // c
template <> void f(int); // d [specialization of a]
void f(double);                               // e

bool b;
int i;
double d;

// specify which function is called and template type parameter
f(b);        // ???
f(i, 42, d); // ???
f(&i);       // ???
f(i);        // ???
f(d);        // ???
```

Don’t Specialize Function Templates!!! (1)

```
template <typename T> // a
void f(T) {
  std::cout << "BT 1\n";
}

template <typename T> // b
void f(T*) {
  std::cout << "BT 2\n";
}

template<>            // c
void f(int*) {
  std::cout << "BT 2"
  "specialization\n";
}

int *p;
f(p); // ???
```

```
template <typename T> // a
void f(T) {
  std::cout << "BT 1\n";
}

template<>            // c
void f(int*) {
  std::cout << "BT 1"
     "specialization\n";
}

template <typename T> // b
void f(T*) {
  std::cout << "BT 2\n";
}

int *p;
f(p); // ???
```

Don’t Specialize Function Templates!!! (2)

- Key to understanding surprising behavior is this: ***Specializations don’t overload; only base templates do!!!***
- Moral #1: If you want to customize function base template and want that customization to participate in overload resolution [or, to always be used in the case of exact match], make it a nontemplate function, not a specialization
- Moral #2: if you do provide overloads, avoid also providing specializations

Review

- What is function template overloading?
- Why overload function templates?
- What is function template specialization