CS100 Recitation 15

GKxx

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Variadic Templates

```cpp
template <typename T>
inline void read(T &x) {
  int c = getchar(), f = 0; x = 0;
  while (!isdigit(c)) {
    f |= c == '-';
    c = getchar();
  }
  while (isdigit(c)) {
    x = x * 10 + c - '0';
    c = getchar();
  }
  if (f) x = -x;
}
template <typename T, typename... Args>
inline void read(T &x, Args &...args) {
  read(x); read(args...);
}
```

Variadic Templates

```
int a; long b; unsigned c; short d;
read(a, b, c, d);
```

Variadic Templates

```
int a; long b; unsigned c; short d;
read(a, b, c, d);
```

The compiler will generate:

```
void read(int &, long &, unsigned &, short &);
void read(long &, unsigned &, short &);
void read(unsigned &, short &);
void read(short &);
void read(int &);
void read(long &);
void read(unsigned &);
```

Pack Expansion

When `Args &...args` becomes

`long &a, unsigned &b, short &c`

the expression `read(args...)` expands to

`read(a, b, c);`

- e.g. `&args...` expands to `&a, &b, &c`.
- e.g. `const_cast<const Args *>(&args)...` expands to

  `const_cast<const T1 *>(&x1), const_cast<const T2 *>(&x2), const_cast<const T3 *>(&x3)`

- `sizeof...(args)` is the number of elements in the parameter pack. (NOT '`sizeof(args)...`'!)

Contents

Specialization: Revisit

Check whether Two Types are Same

```cpp
template <typename X, typename Y>
struct AreSame {
  static constexpr bool value = false;
};
template <typename X>
struct AreSame<X, X> {
  static constexpr bool value = true;
};

AreSame<int, double>::value // false
AreSame<int, signed>::value // true
```

Check whether a Type is a Pointer

```cpp
template <typename T>
struct IsPointer {
  static constexpr bool value = false;
};
template <typename T>
struct IsPointer<T *> {
  static constexpr bool value = true;
};
```

`<type_traits>`

Primary type categories

is_void (C++11)	checks if a type is `void` (class template)
is_null_pointer (C++14)	checks if a type is `std::nullptr_t` (class template)
is_integral (C++11)	checks if a type is an integral type (class template)
is_floating_point (C++11)	checks if a type is a floating-point type (class template)
is_array (C++11)	checks if a type is an array type (class template)
is_enum (C++11)	checks if a type is an enumeration type (class template)
is_union (C++11)	checks if a type is an union type (class template)
is_class (C++11)	checks if a type is a non-union class type (class template)
is_function (C++11)	checks if a type is a function type (class template)
is_pointer (C++11)	checks if a type is a pointer type (class template)
is_lvalue_reference (C++11)	checks if a type is a *lvalue reference* (class template)
is_rvalue_reference (C++11)	checks if a type is a *rvalue reference* (class template)
is_member_object_pointer (C++11)	checks if a type is a pointer to a non-static member object (class template)
is_member_function_pointer (C++11)	checks if a type is a pointer to a non-static member function (class template)

`<type_traits>`

Composite type categories

is_fundamental (C++11)	checks if a type is a fundamental type (class template)
is_arithmetic (C++11)	checks if a type is an arithmetic type (class template)
is_scalar (C++11)	checks if a type is a scalar type (class template)
is_object (C++11)	checks if a type is an object type (class template)
is_compound (C++11)	checks if a type is a compound type (class template)
is_reference (C++11)	checks if a type is either a *lvalue reference* or *rvalue reference* (class template)
is_member_pointer (C++11)	checks if a type is a pointer to an non-static member function or object (class template)

Type properties

is_const (C++11)	checks if a type is const-qualified (class template)
is_volatile (C++11)	checks if a type is volatile-qualified (class template)
is_trivial (C++11)	checks if a type is trivial (class template)
is_trivially_copyable (C++11)	checks if a type is trivially copyable (class template)
is_standard_layout (C++11)	checks if a type is a standard-layout type (class template)
is_pod (C++11)(deprecated in C++20)	checks if a type is a plain-old data (POD) type (class template)
is_literal_type (C++11) (deprecated in C++17) (removed in C++20)	checks if a type is a literal type (class template)

`<type_traits>`

Supported operations

`is_constructible` (C++11) `is_trivially_constructible`(C++11) `is_nothrow_constructible` (C++11)		checks if a type has a constructor for specific arguments (class template)
`is_default_constructible` (C++11) `is_trivially_default_constructible`(C++11) `is_nothrow_default_constructible` (C++11)		checks if a type has a default constructor (class template)
`is_copy_constructible` (C++11) `is_trivially_copy_constructible`(C++11) `is_nothrow_copy_constructible` (C++11)		checks if a type has a copy constructor (class template)
`is_move_constructible` (C++11) `is_trivially_move_constructible`(C++11) `is_nothrow_move_constructible` (C++11)		checks if a type can be constructed from an rvalue reference (class template)
`is_assignable` (C++11) `is_trivially_assignable`(C++11) `is_nothrow_assignable` (C++11)		checks if a type has an assignment operator for a specific argument (class template)
`is_copy_assignable` (C++11) `is_trivially_copy_assignable`(C++11) `is_nothrow_copy_assignable` (C++11)		checks if a type has a copy assignment operator (class template)
`is_move_assignable` (C++11) `is_trivially_move_assignable`(C++11) `is_nothrow_move_assignable` (C++11)		checks if a type has a move assignment operator (class template)
`is_destructible` (C++11) `is_trivially_destructible`(C++11) `is_nothrow_destructible` (C++11)		checks if a type has a non-deleted destructor (class template)
`has_virtual_destructor`(C++11)		checks if a type has a virtual destructor (class template)
`is_swappable_with` (C++17) `is_swappable` (C++17) `is_nothrow_swappable_with`(C++17) `is_nothrow_swappable` (C++17)		checks if objects of a type can be swapped with objects of same or different type (class template)

Examples

Raise a compile-error with customized information text when
Shape is not an abstract class:

```cpp
static_assert(std::is_abstract<Shape>::value,
              "'Shape' must be an abstract class!");
```

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```

std::vector doesn't allow value-type to be cv-qualified:

```cpp
template <typename Tp, typename Alloc>
class vector {
  static_assert(std::is_same<Tp, typename std::remove_cv<
      Tp>::type>::value, "std::vector must have a non-
      const, non-volatile value type!");
  // ...
};
```

Examples

```
template <typename Tp, typename Alloc>
class vector {
  static_assert(std::is_same<Tp, typename std::remove_cv<
      Tp>::type>::value, "std::vector must have a non-
      const, non-volatile value type!");
  // ...
};
```

Why is typename here?

Examples

```
template <typename Tp, typename Alloc>
class vector {
  static_assert(std::is_same<Tp, typename std::remove_cv<
      Tp>::type>::value, "std::vector must have a non-
      const, non-volatile value type!");
  // ...
};
```

Why is `typename` here?

- When `Tp` is unknown, the compiler does not know what
  `std::remove_cv<Tp>` is.

- Is `std::remove_cv<Tp>::type` a type or a `static` data
  member? You tell the compiler.

Examples

```cpp
template <typename T, bool is_const>
class Slist_iterator {
 public:
  using reference = typename std::conditional<is_const,
      const T &, T &>::type;
  using pointer = typename std::conditional<is_const,
      const T *, T *>::type;
};
```

Examples

```
template <typename T, bool is_const>
class Slist_iterator {
 public:
  using reference = typename std::conditional<is_const,
      const T &, T &>::type;
  using pointer = typename std::conditional<is_const,
      const T *, T *>::type;
};
```

How is std::conditional implemented?

Examples

```cpp
template <bool Condition, typename TrueT, typename FalseT>
struct Conditional {
  using type = TrueT;
};
template <typename TrueT, typename FalseT>
struct Conditional<false, TrueT, FalseT> {
  using type = FalseT;
};
```

std::distance

```
template <typename Iterator>
?? distance(Iterator begin, Iterator end);
```

What's the return-type?

std::distance

```
template <typename Iterator>
?? distance(Iterator begin, Iterator end);
```

What's the return-type?

```
typename Iterator::difference_type
```

`std::distance`

Is this correct?

```
template <typename Iterator>
  typename Iterator::difference_type
    distance(Iterator begin, Iterator end) {
  return end - begin;
}
```

std::distance

Is this correct?

```
template <typename Iterator>
  typename Iterator::difference_type
    distance(Iterator begin, Iterator end) {
  return end - begin;
}
```

Yes, but only for random-access-iterators.

std::distance

Recognize and choose different implementations:

- For input-iterators, increment `begin` until it reaches `end` and count the steps.
- For random-access-iterators, return `end - begin`.

std::distance

Recognize and choose different implementations:

- For input-iterators, increment `begin` until it reaches end and count the steps.
- For random-access-iterators, return `end - begin`.

Require every iterator to have a type alias member: `iterator_category`.

- `std::vector<T>::iterator_category` is `std::random_access_iterator_tag`
- `std::list<T>::iterator_category` is `std::bidirectional_iterator_tag`
- `std::forward_list<T>::iterator_category` is `std::forward_iterator_tag`

std::distance

Is this correct?

```cpp
template <typename Iterator>
inline auto distance(Iterator begin, Iterator end)
    -> typename Iterator::difference_type {
  using category = typename Iterator::iterator_category;
  if (std::is_same<category,
                   std::random_access_iterator_tag>::value)
    return end - begin;
  else {
    // ...
  }
}
```

std::distance

Is this correct?

```cpp
template <typename Iterator>
inline auto distance(Iterator begin, Iterator end)
    -> typename Iterator::difference_type {
  using category = typename Iterator::iterator_category;
  if (std::is_same<category,
                   std::random_access_iterator_tag>::value)
    return end - begin;
  else {
    // ...
  }
}
```

It **doesn't work**! Even when Iterator is an input-iterator, the expression 'end - begin' is still compiled and causes an error!

std::distance

```
template <typename Iterator>
auto distance_impl(Iterator begin, Iterator end,
                   std::input_iterator_tag) {
  // ...
}
template <typename Iterator>
auto distance_impl(Iterator begin, Iterator end,
                   std::random_access_iterator_tag) {
  return end - begin;
}
template <typename Iterator>
inline auto distance(Iterator begin, Iterator end) {
  using category = typename Iterator::iterator_category;
  return distance_impl(begin, end, category{});
}
```

- "Compile-time polymorphism".

Traits

Wait... What about pointers?

- Pointers are also iterators,
- but they do not have a 'iterator_category' member!

Traits

Wait... What about pointers?

- Pointers are also iterators,
- but they do not have a 'iterator_category' member!

Define a helper class.

```cpp
template <typename Iterator>
struct Category {
  using type = typename Iterator::iterator_category;
};
template <typename T>
struct Category<T *> {
  using type = std::random_access_iterator_tag;
};
```

Traits

```cpp
template <typename Iterator>
struct Category {
  using type = typename Iterator::iterator_category;
};
template <typename T>
struct Category<T *> {
  using type = std::random_access_iterator_tag;
};
template <typename Iterator>
inline auto distance(Iterator begin, Iterator end) {
  return distance_impl(begin, end,
                       typename Category<Iterator>::type{});
}
```

std::iterator_traits

The standard library has defined std::iterator_traits:

```
template <typename Iterator>
struct iterator_traits {
  using value_type = typename Iterator::value_type;
  using difference_type
      = typename Iterator::difference_type;
  using pointer = typename Iterator::pointer;
  using reference = typename Iterator::reference;
  using iterator_category
      = typename Iterator::iterator_category;
};
```

`std::iterator_traits`

Specialization of `std::iterator_traits` for pointers:

```cpp
template <typename T>
struct iterator_traits<T *> {
  using value_type = T;
  using difference_type = std::ptrdiff_t;
  using pointer = T *;
  using reference = T &;
  using iterator_category
      = std::random_access_iterator_tag;
};
```

Contents

Test whether a Function Exists

SFINAE: Substitution Failure Is Not An Error

- When substitution failure happens, the compiler tries some other solutions instead of reporting an error.

Test whether a Function Exists

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Test whether a Function Exists

SFINAE: Substitution Failure Is Not An Error

- When substitution failure happens, the compiler tries some other solutions instead of reporting an error.
- If we can transform an error into a substitution failure...

```
namespace detail {
  template <typename T = Expr,
            typename = decltype(make_sin((T *)nullptr))>
  std::true_type helper(int);
  std::false_type helper(double);
}
constexpr bool make_sin_defined
    = decltype(detail::helper(0))::value;
```

- That's how things like std::is_copy_constructible are implemented.

Test whether a Member Function is `const`

```cpp
namespace detail {
  template <typename T = Point_handle,
            typename = decltype(((const T *)nullptr)->
                get_x())>
  std::true_type helper(int);
  std::false_type helper(double);
}
constexpr bool get_x_is_const
    = decltype(detail::helper(0))::value;
static_assert(get_x_is_const, "Why don't you define get_x
    as a const member function?");
```

std::enable_if

```
// enable_if<...>::type does not exist when condition is
    false
template <bool Condition, typename T>
struct enable_if {};
template <typename T>
struct enable_if<true, T> {
  using type = T;
};
```

std::enable_if

```cpp
// enable_if<...>::type does not exist when condition is
    false
template <bool Condition, typename T>
struct enable_if {};
template <typename T>
struct enable_if<true, T> {
  using type = T;
};
```

Enable a function to be called according to a given condition:

```cpp
template <typename T>
inline auto read(T &x) // Only allow T to be integral type
    -> typename std::enable_if<std::is_integral<T>::value,
                               void>::type {
  // ...
}
```

std::enable_if

Allow conversion from `iterator` to `const_iterator`:

```cpp
template <typename T, bool is_const>
class Slist_iterator {
 public:
  template <typename Other,
            typename = typename std::enable_if<
                std::is_same<Slist_iterator<T, false>,
                             Other>::value
                && is_const>::type>
  Slist_iterator(const Other &oi);
};
```

Contents

Compile-time Factorial

Compile-time factorial:

```cpp
template <unsigned N>
struct Factorial {
  static constexpr unsigned value
      = N * Factorial<N - 1>::value;
};
template <>
struct Factorial<0> {
  static constexpr unsigned value = 1;
};
```

You may use it like this:

```cpp
std::cout << Factorial<5>::value;  // prints 120
std::cout << Factorial<10>::value; // prints 3628800
```

The results are calculated during compile-time!

What can it Accomplish?

Examples:

- Ensuring dimensional unit correctness
- Optimizing matrix operations
- Generating custom design pattern implementations
- Designing "domain-specific embedded languages" (DSEL).

A Simple Example: Dimensions

From *C++ Template Metaprogramming* Chapter 3:

```cpp
#include "dimensions.hpp"
#include <iostream>
int main() {
    quantity<double, mass> m(3.0);
    quantity<double, force> f(6.0);
    quantity<double, acceleration> a(2.0);
    quantity<double, force> f2 = m * a;
    std::cout << f2.value() << std::endl;
    std::cout << (m * a == f) << std::endl;
    f += -m * a + f;
    std::cout << f.value() << std::endl;

    // This should cause a compile-error.
    std::cout << (m + f).value() << std::endl;
    return 0;
}
```

Contents

Summary

What Have We Learned?

1. Getting Started	
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3. Strings, Vectors, and Arrays	
4. Expressions	
5. Statements	Exception handling (try-catch, throw)
6. Functions	
7. Classes	
8. The IO Library	
9. Sequential Containers	
10. Generic Algorithms	Lambdas
11. Associative Containers	
12. Dynamic Memory	Smart pointers
13. Copy Control	Rvalue references and move semantics
14. Overloaded Operations and Conversions	
15. Object-Oriented Programming	
16. Templates and Generic Programming	Type deduction related to rvalue refs
17. Specialized Library Facilities	
18. Tools for Large Programs	
19. Specialized Tools and Techniques	

Exception Handling

- `try-catch`, `throw` and the exception classes defined in the standard library
- *Effective C++* Item 8, 25, 29.

new and delete

- Customize `new` and `delete`?
  - You may want to detect usage errors, e.g. memory leak.
  - You may have a good understanding of your program's dynamic memory usage patterns, and have a better way of allocating/deallocating memory that can improve efficiency.
  - You may want to collect usage statistics.
    - What is the distribution of allocated block sizes?
    - What is the distribution of their lifetimes?
    - In what order do they tend to be allocated and deallocated?
    - What is the high water mark?

- `new` and `delete` with extra arguments?

https:
//blog.csdn.net/qq_39677783/article/details/124704501

Concurrency

Multi-threading in C++: `<thread>`, `<future>`, . . . (since C++11)

```cpp
int calculate_sum(const int *a, int n) {
  int sum[4] = {0};
  std::vector<std::thread> th;
  int block_size = n / 4;
  for (auto i = 0; i != 4; ++i)
    th.emplace_back(
        [a](int left, int right, int &s) {
          for (auto j = left; j != right; ++j)
            s += a[j];
        }, block_size * i, block_size * (i + 1),
           std::ref(sum[i]));
  for (auto &t : th) t.join();
  for (int i = block_size * 4; i < n; ++i)
    sum[0] += a[i];
  return sum[0] + sum[1] + sum[2] + sum[3];
}
```

The Boost Library

A collection of high quality, open source, platform- and compiler-independent libraries. `http://boost.org`

- Lambda: (Unlike C++11 lambda)

```
std::for_each(v.begin(), v.end(),
              std::cout << _1 * 2 + 10 << '\n');
```

- Template metaprogramming library (mpl)
- Math and numerics
- Inter-language support (e.g. boost python)
- Memory management
- Graph library
- ......