CS100 Recitation 15

GKxx

June 6, 2022

Contents

Contents

Variadic Templates

```
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

Check whether Two Types are Same

```
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

```
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 a 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:

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

Examples

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

```
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

```
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

```
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?

```
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?

```
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,
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Define a helper class.

```
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

```
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:

```
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

```
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

```
// 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:

```
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:

```
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:

```
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:

```
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:

```
#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;
}
```

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What Have We Learned?

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3. Strings, Vectors, and Arrays	
4. Expressions	
5. Statements	Exception handling (try-catch, throw)
6. Functions	
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8. The IO Library	
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10. Generic Algorithms	Lambdas
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12. Dynamic Memory	Smart pointers
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16. Templates and Generic Programming	Type deduction related to rvalue refs
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Summary

- Chapter 4. Smart Pointers
  - Item 18: Use std::unique_ptr for exclusive-ownership resource management.
  - Item 19: Use std::shared_ptr for shared-ownership resource management.
  - Item 20: Use std::weak_ptr for std::shared_ptr-like pointers that can dangle.
  - Item 21: Prefer std::make_unique and std::make_shared to direct use of new.
  - Item 22: When using the Pimpl Idiom, define special member functions in the implementation file.
- Chapter 5. Rvalue References, Move Semantics, and Perfect Forwarding
  - Item 23: Understand std::move and std::forward.
  - Item 24: Distinguish universal references from rvalue references.
  - Item 25: Use std::move on rvalue references, std::forward on universal references.
  - Item 26: Avoid overloading on universal references.
  - Item 27: Familiarize yourself with alternatives to overloading on universal references.
  - Item 28: Understand reference collapsing.
  - Item 29: Assume that move operations are not present, not cheap, and not used.
  - Item 30: Familiarize yourself with perfect forwarding failure cases.
- Chapter 6. Lambda Expressions
  - Item 31: Avoid default capture modes.
  - Item 32: Use init capture to move objects into closures.
  - Item 33: Use decltype on auto&& parameters to std::forward them.
  - Item 34: Prefer lambdas to std::bind.
- Chapter 7. The Concurrency API
  - Item 35: Prefer task-based programming to thread-based.
  - Item 36: Specify std::launch::async if asynchronicity is essential.
  - Item 37: Make std::threads unjoinable on all paths.
  - Item 38: Be aware of varying thread handle destructor behavior.
  - Item 39: Consider void futures for one-shot event communication.
  - Item 40: Use std::atomic for concurrency, volatile for special memory.

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)

```
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
- .....