Part V

 $C_{++}11/14/17$

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Advanced C++



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Variadics





🔟 Non-class Templating

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- Macros can now have a variable number of arguments in C++11: #define PRINT(X, ...) printf(X "\n", __VA_ARGS__); int main(void) { PRINT("Error: %s", "Message"); PRINT("Error: %s %d", "Message", 42); }
- __VA_ARGS__ is replaced by all the remaining parameters to the macro.
- This is not a good example of its use, and I am unable to think of one. This suggests you should not use it...
- See Examples/variable_macros.C

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Variadic templates

• Templates can now have a variable number of template parameters void print () {}

```
template<typename T, typename... Args>
void print(const T& t, Args... a) {
  std::cout << t << std::endl;
  print(a...);
}
int main(void) {
  print("Hello", 10.9, 11u);
}</pre>
```

- The ... syntax indicates that the parameter pack Args is expanded.
- The ... syntax can be used wherever a list of elements is required.

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Variadic templates...

Example use of variadic templates to create custom version of std::tuple:

```
template<typename... Params> struct Tuple;
template<typename T, typename... OtherParams>
struct Tuple<T, OtherParams...> : Tuple<OtherParams...>{
          Tuple(T p, OtherParams... o) : Tuple<OtherParams...>(o...),
                   param(p) {
          template<int N>
          typename std::enable_if<(N > 0), typename EltType<(N > 0) ?
                   N-1 : 0, OtherParams...>::type>::type get()const{
                     return Tuple<OtherParams...>::template get<N-1>();
           }
          template<int N>
          typename std::enable_if<N == 0, T>::type
          qet()const{
                     return param;
                   param;
                                                                                                                                                                                                                                                     A B A A B A
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```

Variadic templates...

• Extraction of the N'th type from a parameter pack as used in the previous slide:

```
template<int N, typename... Elts> struct EltType;
template<int N, typename T, typename... Elts>
struct EltType<N, T, Elts...>{
  typedef typename EltType<N-1, Elts...>::type type;
};
//! Recursion-ending specialisation
template<typename T, typename... Elts>
struct EltType<0, T, Elts...>{
  typedef T type;
};
```

- See Examples/variadic_tuple.C.
- Use t.get<1>() to access element 1 of the tuple.

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Variadic templates...
```

• As a further example of the power of parameter packs:

```
template<typename F, typename... Args>
double fIncreased(F f, Args... x) {
  return f((x+1)...);
}
std::cout << "f(4,5,6) = " << fIncreased(f, 3,4,5) << std::endl;</pre>
```

- The (x+1)... translates into x+1 for each of Args.
- See Examples/variadic_templates.C

Folding expressions

- The following works from C++17 only
- When using template parameter packs, you may wish to apply an operation to combine all elements into one:

```
template<typename... T>
int sum(T... b) {
  return (b + ...);
}
```

produces a function that sums all values passed to it, and is known as a unary right fold.

• Most operators can be used here, and can have initial left or right operands:

```
template<typename... T>
int startMinusSum(int a, T... b){
  return (a - ... - b);
}
```

and this is known as a binary left fold.

Folding expressions ctd

• However:

```
template<typename... T>
bool equal(T... b) {
  return (b == ...);
}
```

does not do what you want: b1 == b2 == b3 is unlikely to be useful.

- In fact gcc produces an error with this case due to lack of parentheses.
- In this case, the answer is to write:

```
template<typename S, typename... T>
bool equal2(S a, T... b){
  return ( (a == b) && ... );
}
```

• See Examples/folding_expr.C for full code.

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Empty folding expressions

- What happens if there are no arguments to a folding expression?
- For && the answer is true
- For || the answer is false
- For , the answer is void()
- For example, an empty sum is undefined. The answer is not zero, as for non-numeric arguments, the identity element for addition may not be equivalent to zero.
- Similarly, an empty multiplication is not 1.







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Templated aliases

• In C++11, typedefs can be templated:

```
template<typename T>
using ListConstIter = typename std::list<T>::const_iterator;
```

• This provides a shorthand for a constant iterator over a list of elements of type T.

```
std::list<int> a{0,6,9,13,-14};
ListConstIter<int> b = a.begin();
```

- This particular example is probably better done with **auto**, but the principle stands.
- See templated_typedef.C.

Templated variables

- As well as templated functions, classes, and types, C++14 also allows templated variables.
- This may seem odd at first; surely the value of a variable defines its type, and templating it is worthless?
- However:

```
template<typename T> T epsilon = 0;
template<> float epsilon<float> = 1e-6;
template<> double epsilon<double> = 1e-12;
```

could be useful, instead of using something dependent on
std::numeric_limits

- See Examples/templated_variables.C
- Other examples include a Matrix<T>-type with an identity defined for a number of types T.

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Part VI

 $C_{++}14$ specific

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• Binary literals may now be specified as:

int answer = 0b101010; // answer = 42

• Groups of digits can be separated using ': int billion = 1'000'000'000;

This is for readability purposes only (and may not play well with automatic highlighting in your text-editor).

• See Examples/literals.C

Attributes

- Functions, variables, types, and other C++ constructs are permitted to have attributes; extra information not inherent in their definition.
- Many compilers support their own attributes, typically providing hints that may improve performance.
- As of C++14, the only attributes allowed are:
 - [[noreturn]] For functions that never return
 - [[deprecated("reason")]] (where "reason" may be omitted) provides a compile-time warning that a function is deprecated
- For example, this may allow the compiler to make certain optimizations.

Attributes ctd

• Or, for functions you want to discourage yourself or others from using:

```
[[deprecated("Use the more general iterator form.")]]
void sort(const std::vector<int>& a)
{
}
```

will print a message at compile time, if the function is used:

```
void sort(std::vector<int>&) is deprecated:
Use the more general iterator form
```

```
• See Examples/attributes.C for full code.
```

- Compilers may also support their own attributes.
- Those supported by gcc include (in any C++ version):
 - [[gnu::aligned(32)]] to align x on a memory address a multiple of 32 bytes.
 - int myTmp [[gnu::unused]]; to suppress a compiler warning that a variable is unused.

Return type deduction

- The auto keyword in C++11 only applied to variables and to functions with decltype.
- C++14 allows the return type of any function to be deduced automatically:

```
template<typename T, typename S>
auto product(T t, S s){
  return t * s;
}
```

• If used within a header file, the function definition must be seen before it is used (to deduce the return type).

Return type deduction ctd

• Also, since C++ parsing is top-to-bottom, recursive functions must be arranged carefully:

```
auto factorial(int i){
    if(i<= 1){
        // Return type deduced to be 'int' here.
        return 1;
    }
    else{
        return factorial(i-1) * i;
    }
}</pre>
```

works, but reversing the if statement fails because the return type must be deduced first.

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- See Examples/return_type_deduction.C for details.
- I suggest that **auto** is used sparingly, and only to avoid long typenames, or typenames deduced from template-constructs.

auto lambda parameters

• In C++11 lambda function parameters had to have an explicit type; now they can have **auto** type:

so that we do not need to explicitly find the value_type of data.

• Also, lambda functions without local capture can be converted to C-style function pointers:

```
auto f = [](auto x){return x + 5;};
int (*add5)(int) = f;
float (*add5f)(float) = f;
```

- giving two concrete function pointers that add 5 to either an integer or a float.
- See Examples/lambda_14.C for full example.

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• If a class/struct is initialized using an initializer list, then values defined in the class are used if the aggregate does not contain enough:

struct X{ int a; int b; int c = 9; }; X x = {2, 3};

- The above will fail to compile in C++11 (c cannot be initialized), but will succeed in C++14 (c = 9).
- Of course, X y; will succeed in any C++ version.

Part VII

C++17 specific

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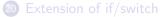
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Outline



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Preprocessor

- Trigraphs are no longer allowed. For example, ??= was equivalent to # in earlier C++ standards. This was for very old small keyboards without certain characters.
- The <u>__has_include</u> expression is supported to test whether a particular header file is available within the header search path:

```
#if __has_include(<qt4/Qt/qconfig.h>)
#define HAVE_QT
#endif
```

• I would suggest that a proper appreciation of autoconf, GNUMake, CMake, and similar tools would be of more use.

Minor clean-ups

- The operator ++ on a boolean type no longer exists.
- The **register** keyword is now removed; you can use it as a variable name. In C it indicates that a variable should be put in a CPU register. In practice it now makes little difference to performance in C anyway.

The following minor modification of static_assert is now supported:

```
template<int D>
class A{
   static_assert(D >= 0);
};
```

I.e. without the human-readable message required in C++11.



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Hexadecimal floating point literals

For some purposes, it is useful to specify floating point numbers w.r.t. base 2:

```
const double quarter = 0x1.0p-2;
double three_eighths = 0x0.cp-1;
```

The first should be obvious; the second expands in binary as $(\frac{1}{2} + \frac{1}{4}) \times 2^{-1}$ since 0xc = 1100b.

```
std::cout << std::hexfloat <<
    std::numeric_limits<double>::epsilon()
```

displays 0x1p-52 since double-precision has machine epsilon 2^{-52} .

byte type

- In order to allow clearer distinction between numbers for arithmetic or text (char, unsigned char) and pure memory storage, C++17 introduces std::byte.
- It is defined as:

enum class byte : unsigned char {};

```
• and can be used as:
```

```
std::byte a{0x49};
std::vector<std::byte> v(10, a);
std::cout << "v[3]=" << std::hex << (int)v[3] << std::endl;</pre>
```

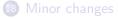
• Note the casting required not to print as a text character.



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Attributes

Outline





D Extension of if/switch

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Attributes

- C++17 introduces further attributes:
- [[fallthrough]] suppress potential compiler warning when case statements allow fall-through.

```
int input;
switch(input){
   case 1:
   case 3:
    std::cout << "Input is less than 4" << std::endl;
    [[fallthrough]];
   case 5:
    std::cout << "Input is odd" << std::endl;
    break;
}
```

• Without the attribute, this could cause the compiler to produce a warning or error.

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attributes

- [[nodiscard]] Causes compiler to give warning if a value returned from a function is ignored.
- [[maybe_unused]] Marks a variable or function parameter as unused, which allows compiler to suppress a warning about unused variables.

```
template<typename T>
[[nodiscard]] bool sendMsg([[maybe_unused]] const T* src,
     [[maybe_unused]] size_t n) {
   return false;
}
```

- where the sendMsg function returns success or failure error code.
- We could leave the variables un-named, but what if we want to document them (e.g. with Doxygen)?
- See Examples/attributes_17.C for full code.
- Also note that attributes can be applied to namespaces and enumerators, but none are given in the standard.

 Multiple attributes in the same namespace can be specified as: int myTmp [[using gnu: unused, aligned(32)]]; instead of int myTmp [[gnu::unused, gnu::aligned(32)]];



Construction of aggregates

- C++ has always allowed aggregate initialization: struct S{int s; double f;}; S a{42, 3.142};
- However, only from C++17 is initialization of base-classes using this approach allowed:

```
struct Name : S{ std::string n; };
Name n{ {10, 2.3}, "Ford"};
```

- The first element corresponds to the initialization of the base-class
 S. The second corresponds to the element n.
- Multiple base-classes are supported, in order: struct Nested : S, Name { char a; }; Nested p{ {10, 3.2}, { {9, 1.2}, "Frankie" }, 'b' };
- Note that virtual base-classes are not allowed to be initialized in this way.
- See Examples/aggregate_init.C for full code.

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inline variables

- Now allowed to have multiple definitions of extern variables, so long as they have inline, and there is a definition of the variable in each translation unit in which it is used.
- Similar to inline functions

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New versions of if and switch

• In some cases, you may have an if or switch statement that depends on a variable whose value is not needed outside the test:

```
auto iter = myMap.find(10);
if( iter != myMap.end() ) {
  return iter->second;
}
else{
  std::cout << "Key 10 not found" << std::endl;
}
```

• This can now be rewritten:

```
if( auto iter = myMap.find(10); iter != myMap.end() ){
  return iter->second;
}
else{
  std::cout << "Key 10 not found" << std::endl;
}</pre>
```

New versions of if and switch

- The advantage is that iter does not leak into the surrounding scope. It is not needed outside of the if scope.
- This could be more important if initialization of iter required some form of resource allocation that should be released after the if.
- Similarly, switch(init ; testvalue) exists.
- See Examples/if_17.C for full code.