

Familiar template syntax for generic lambdas

Document #: D0428R0
Date: 2016-09-08
Project: Programming Language C++
Audience: Evolution Working Group
Reply-to: Louis Dionne <ldionne.2@gmail.com>

1 Introduction

C++14 added the ability to define generic lambdas, i.e. lambdas where the `operator()` of the generated *closure-type* is a template. This addition was initially proposed in [N3418], which included many different features for generic lambdas, including the functionality proposed by this paper. However, N3418 was not accepted as-is and its successor, [N3559], was accepted instead. N3559 settled on the `auto`-based syntax that we know in C++14 for defining generic lambdas, leaving the usual template syntax out for lack of clear use cases (according to an author of N3559):

```
[] (auto x) { /* ... */ }
```

Unfortunately, this syntax makes it difficult to interact with the type of the parameter(s) and lacks flexibility that is sometimes required, as outlined in the [Motivation](#) section. Hence, this paper proposes adding the ability to use the familiar template syntax when defining lambda expressions:

```
[] <typename T> (T x) { /* ... */ }  
>[] <typename T> (T* p) { /* ... */ }  
>[] <typename T, int N> (T (&a)[N]) { /* ... */ }
```

2 Motivation

There are a few key reasons why the current syntax for defining generic lambdas is deemed insufficient by the author. The gist of it is that some things that can be done easily with normal function templates require significant hoop jumping to be done with generic lambdas, or can't be done at all. The author thinks that lambdas are valuable enough that C++ should support them just as well as normal function templates. The following details such areas where lambdas are lacking in their current form:

1. The limited form of "pattern matching" on template argument allowed by C++ in function templates is very useful, and it would be equally useful to allow it in lambda expressions. For example, writing a lambda that accepts a `std::vector` containing elements of any type (but not another container) is not possible with the current syntax for generic lambdas. Instead, one must write a catch-all generic lambda that accepts any type, and then assume that it is of the proper type, or check that it is not through other means:

```

template <typename T> struct is_std_vector           : std::false_type { };
template <typename T> struct is_std_vector<std::vector<T>> : std::true_type { };

auto f = [](auto vector) {
    static_assert(is_std_vector<decltype(vector)>::value, "");
};

```

In addition to being verbose, calling the lambda with a type that is not a `std::vector` will result in a hard error inside the body of the lambda, not a template argument deduction failure. This does not play nicely with other parts of the language such as SFINAE-based detection, and it is obviously not as clear as the equivalent function template.

Another instance where "pattern matching" would be useful is to deconstruct the type of arguments that are template specializations. For example, imagine that we want to get the type of elements stored in the vector in the previous example. Right now, we'd have to write this:

```

auto f = [](auto vector) {
    using T = typename decltype(vector)::value_type;
    // ...
};

```

This is cumbersome syntax-wise, and it requires the type to provide a nested alias that does just the right thing. This is not a problem for `std::vector`, but most types don't provide such aliases (and in many cases it wouldn't make sense for them to). Hence, right now, types that do not provide nested aliases or accompanying metafunctions can simply not be deconstructed in lambdas. Instead, it would be much simpler and more flexible to write

```

auto f = []<typename T>(std::vector<T> vector) {
    // ...
};

```

2. It is often useful to retrieve the type of the parameter of a generic lambda, e.g. for accessing a static member function or an alias nested inside it. However, retrieving such a type requires using `decltype`, which includes its reference and cv qualifiers. This can often lead to unexpected results:

```

auto f = [](auto const& x) {
    using T = decltype(x);
    T copy = x;
    T::static_function();
    using Iterator = typename T::iterator;
};

```

// Compiles, but wrong semantics!
// Does not compile!
// Does not compile!

To work around this unfortunate situation, one must introduce some amount of verbosity:

```

auto f = [](auto const& x) {
    using T = std::decay_t<decltype(x)>;
    T copy = x;
    T::static_function();
};

```

```

    using Iterator = typename T::iterator;
};

```

Furthermore, this problem compounds when trying to make a parameter type dependent on a previous parameter type, because aliases can't be introduced in that context to reduce verbosity:

```

auto advance = [](auto& it,
                  typename std::decay_t<decltype(it)>::difference_type n) {
    // ...
};

```

Instead, it would be much nicer and closer to usual templates if we could simply write

```

auto f = []<typename T>(T const& x) {
    T copy = x;
    T::static_function();
    using Iterator = typename T::iterator;
};

auto advance = []<typename It>(It& it, typename It::difference_type n) {
    // ...
};

```

3. Perfect forwarding in generic lambdas is more verbose than it needs to be, and the syntax for it is different from what's usually done in normal function templates. While this is technically a direct corollary of the previous point, the author thinks this is sufficiently annoying to be worth mentioning separately. The problem is that since the only way to get an argument's type in a lambda is to use `decltype`, we must resort to the following syntax for perfect forwarding:

```

auto f = [](auto&& ...args) {
    return foo(std::forward<decltype(args)>(args)...);
};

```

Exactly why this works is explained in a blog post written by Scott Meyers [\[Meyers\]](#), but the very fact that Meyers had to write a blog post about it is telling. Indeed, the interaction between template argument deduction and reference collapsing rules is already sufficiently complicated that many C++ users would benefit from the cognitive load reduction allowed by a single perfect forwarding syntax for both lambdas and normal functions:

```

auto f = []<typename ...T>(T&& ...args) {
    return foo(std::forward<T>(args)...);
};

```

3 Proposed Wording

Change in 5.1.5 `[expr.prim.lambda]/1`:

lambda-expression:

lambda-introducer `<template-parameter-list>opt` *lambda-declarator_{opt}* *compound-statement*

Define the term *template lambda* in 5.1.5 [expr.prim.lambda], just after paragraph 5:

A *template lambda* is a *lambda-expression* specifying a *template-parameter-list*. A *template lambda* is a *generic lambda*, but not the other way around. The `auto` *type-specifier* shall not appear as one of the *decl-specifiers* in the *decl-specifier-seq* of a *parameter-declaration* of a *template lambda*.

We make sure that a *template lambda* is considered a *generic lambda* so that almost all existing wording for *generic lambdas* applies as-is to *template lambdas*. Furthermore, the restriction on `auto` not appearing in the parameters of a *template lambda* is explained in the [Discussion](#) below.

Change in 5.1.5 [expr.prim.lambda]/6:

The closure type for a non-generic *lambda-expression* has a public inline function call operator (13.5.4) whose parameters and return type are described by the *lambda-expression*'s *parameter-declaration-clause* and *trailing-return-type* respectively. The closure type for a *template lambda* has a public inline function call operator member `template` (14.5.2) whose *template-parameter-list*, parameters and return type are described by the *lambda-expression*'s *template-parameter-list*, *parameter-declaration-clause* and *trailing-return-type* respectively. For a generic lambda that is not a *template lambda*, the closure type has [...]

Change in 5.1.5 [expr.prim.lambda]/7:

[...] For a generic lambda with no *lambda-capture*, the closure type has a conversion function template to pointer to function. The conversion function template has the same `invented` *template-parameter-list*, and the pointer to function has the same parameter types, as the function call operator template. [...]

4 Implementation experience

This extension to generic lambdas had been implemented in GCC in 2009 as part of an experiment [\[GCC\]](#). Thus, it seems implementable.

5 Discussion

There were very few controversial decisions to make in the writing of this paper. The only one was whether to allow a lambda to contain both a *template-parameter-list* and conventional `auto`-based parameters. If we were to allow mixing both syntaxes, we would have to decide what the function call operator of the closure type should look like for such lambdas. Some use cases suggest an easy answer, but others are more problematic:

```

[]<typename T>(T, auto) // => template <typename T, typename Invented>
[]<typename T>(auto, T) // => template <typename Invented, typename T>
[]<typename T>(auto)    // which of the above?

```

Note that it *does* make sense to write the third lambda expression, because we can access the function call operator of a lambda explicitly and thus specify a value for T:

```

auto f = []<typename T>(auto x) { };
f.operator()<int, char>(...);
// Should `T` be `int` or `char`? And what about the `auto` parameter?

```

Faced with this, the author saw two solutions

1. Disallow mixing the proposed template syntax with `auto`-based parameters.
2. Arbitrarily decide of an order.

In addition, the decision taken here should be consistent with any potential support for `auto` parameters in normal functions, and also with the proposal for Concepts [N4553]. Given the uncertainty of what's to come, we prefer the first option, which will be trivial to change later on once we know exactly what we want.

6 Acknowledgements

TODO

7 References

- [N4606] Richard Smith, Working Draft, Standard for Programming Language C++
<https://github.com/cplusplus/draft/blob/master/papers/n4606.pdf>
- [Meyers] Scott Meyers, C++14 Lambdas and Perfect Forwarding
<http://scottmeyers.blogspot.com.tr/2013/05/c14-lambdas-and-perfect-forwarding.html>
- [N3418] Faisal Vali, Herb Sutter, Dave Abrahams, Proposal for Generic (Polymorphic) Lambda Expressions
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2012/n3418.pdf>
- [N3559] Faisal Vali, Herb Sutter, Dave Abrahams, Proposal for Generic (Polymorphic) Lambda Expressions (Revision 2)
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2013/n3559.pdf>
- [GCC] Adam Butcher, Latest experimental polymorphic lambda patches
<http://gcc.gnu.org/ml/gcc/2009-08/msg00174.html>
- [N4553] Andrew Sutton, Working Draft, C++ extensions for Concepts
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2015/n4553.pdf>