

Wording for lambdas in unevaluated contexts

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1 Revision history

- R0 – Initial draft
- R1 – Changed the wording to work around the resolution of [DR1607], which conflicted with the initial wording. Also address the potential additional concerns raised by this wording change.
- R2 – Applied feedback from EWG and CWG in Issaquah and CWG in Kona:
 - A lambda expression is not part of the immediate context.
 - Add a discussion about lambdas as non-type template arguments.
 - Clarify the difference between the types of lambda expressions in alias templates.
 - Clarify ODR-equivalence of lambda expressions declared in different TUs, and the meaning for function template declarations.
 - Clarify the situation for redeclarations of functions with lambda-expressions.
 - Rebase on top of the C++17 DIS.
 - Editorial: extract the wording into its own section.
- R3 – Applied changes per guidance from CWG in Toronto:

- Editorial: hyphenate the term full-expression, italicize the term *lambda-expression*, and remove sections useless for wording purposes.
- Replace wording in **[temp.over.link]** by equivalent but much simpler wording as suggested by Richard Smith.
- Add a discussion about implicit captures in *lambda-expressions* in unevaluated contexts.
- R4 – Applied changes per guidance from CWG in Albuquerque:
 - Editorial: do not italicize the “s” in *lambda-expressions*.
 - Use “not considered equivalent” instead of “differ” in example added to **[temp.over.link]**.
 - Clarify why closure types are not given a name for linkage purposes in **[dcl.typedef]**.
 - Add discussion about *requires-clauses* involving *lambda-expressions*.
 - Add note to **[basic.def.odr]** to clarify the situation for non-function templates.
 - Fix example of ODR violation in the discussion (section 6).

2 Discussion on wording

The core language changes introduced in this paper are a bit tricky. The reason is that we remove many restrictions on lambda expressions, yet we still want to keep closure types out of the signature of external functions, which would be a nightmare for implementations. This discussion goes over all known possible points of contingency to clarify them.

1. (wording) With the removal of the restrictions on lambdas in unevaluated contexts, a concern is that lambda-expressions might then be able to appear in the signature of functions with external linkage, which would require implementations to generate a name for the associated closure type. However, since we wouldn’t be able to attach to another ABI entity in some cases (such as lambda-expressions appearing at global scope), that would mean coming up with a mangling scheme that identifies the closure type from nothing but its own form. This, in turn, would require encoding its complete definition, which is burdensome for implementations and motivated the original restrictions on lambda-expressions.

Fortunately, this specific problem can’t arise in the case of non-template functions, even with the above removal of constraints on lambda-expressions. Indeed, according to **[basic.link] 6.5/8**, closure types have no linkage, and therefore they cannot appear in the signature of a function with external linkage (a function is a compound type):

[...] A type is said to have linkage if and only if:
 [...]

- it is a compound type (6.9.2) other than a class or enumeration, compounded exclusively from types that have linkage; or

 [...]

However, to make it clear that closure types are never given a name for linkage purposes, we propose [modifying \[dcl.typedef\]](#).

2. (wording) Another similar problem is that of lambda-expressions appearing in the signature of function templates. There are two ways this could happen. First, a lambda expression could appear not by itself, but indirectly, by being part of an expression which references a template parameter. Indeed, per [\[temp.over.link\] 17.5.6.1/4](#):

When an expression that references a template parameter is used in the function parameter list or the return type in the declaration of a function template, the expression that references the template parameter is part of the signature of the function template.

Thus, a function template declaration such as the following will require the implementation to make the lambda-expression part of the signature, which is specifically what we would like to avoid:

```
template <int N>
void f(const char (*s)[[] {}, N]) { }
```

The other situation we would like to avoid is for implementations to have to figure out that the two following expressions are equivalent, either for linkage purposes (in different translation units) or for redeclaration purposes (in the same translation unit):

```
template <int N> void f(const char (*s)[[] { return N; }]() ) { }
template <int N> void f(const char (*s)[[] { return N; }]() ) { }
```

This case is slightly different from the first one, since the template parameter appears in the body of the lambda-expression, which is not considered part of the full-expression in the function parameter list. To make sure these cases do not happen, we propose [amending \[temp.over.link\]](#).

3. Another possible concern is the appearance of lambda-expressions in contexts that are constrained by the ODR. For example:

```
// a.h:
template <typename T>
int counter() {
    static int cnt = 0;
    return cnt++;
}

inline int f() {
    return counter<decltype([] {})>();
}

// translation unit 1:
#include "a.h"
int foo() { return f(); }

// translation unit 2:
#include "a.h"
```

```
int bar() { return f(); }
```

Given such code, a question might be whether `foo` and `bar` modify the same `cnt` variable, since `f` is defined in a header and it calls `counter` with a closure type that is supposed to be unique. However, since `f` is `inline`, the resulting program is as-if there was a single definition of it, and so both functions end up modifying the same `cnt` variable. This turns out not to be a problem for implementations, because they must already handle such cases where there is an ODR context to attach the closure type to. Thus, no wording change is required.

4. (wording) A concern with allowing lambda-expressions in *declarations* is that of dealing with entities that can be redeclared. It is already the case that no two lambda-expressions share the same closure type within a single translation unit:

```
static decltype([] { }) f();
static decltype([] { }) f(); // invalid; return type mismatch

static decltype([] { }) g();
static decltype(g()) g(); // okay

static void h(decltype([] { }) *) { }
static void h(decltype([] { }) *) { }
h(nullptr); // ambiguous

using A = decltype([] { });
static void i(A *);
static void i(A *) { }
i(nullptr); // okay
```

By further clarifying that the lambda-expressions in alias template specializations are unique to each specialization even if non-dependent, we conclude the following:

```
template <typename T>
using B = decltype([] { });
static void j(B<char16_t> *) { }
static void j(B<char32_t> *) { }
j(nullptr); // ambiguous
```

To make the above interpretation of the standard more obvious, we propose [modifying \[temp.alias\]](#).

Furthermore, some questions were raised on the Core reflector regarding redeclarations like this:

```
template <int N> static void k(decltype([]{ return 0; }()));
template <int N> static void k(decltype([]{ return 0; }())); // okay
template <int N> static void k(int); // okay
```

These should be valid redeclarations, since the lambda expressions are evaluated, and they neither contain a template parameter in their body nor are part of a full-expression that

contains one. Hence, the lambda-expression does not need to appear in the signature of the function, and the behavior is equivalent to this, without requiring any special wording:

```
struct lambda { auto operator()() const { return 0; } };
template <int N> static void k(decltype(lambda{}()));
template <int N> static void k(decltype(lambda{}())); // okay today
template <int N> static void k(int);                  // okay today
```

5. (wording) A concern with allowing lambda-expressions *outside the body of the declaration of function templates* is the need to evaluate the validity of potentially complex expressions as part of template argument deduction. Indeed, without clarifying the wording, it is unclear whether implementations would be expected to support *SFINAE* based on the validity of the body of a lambda-expression found in the declaration of a function template. Since this could be unwieldy for implementations, we choose not to require this in the current paper. Thus, if a lambda-expression appears inside the declaration of a function template and any part of it is ill-formed, then the program is ill-formed. To reflect this, we propose [adding a note at the end of \[temp.deduct\]](#).
6. (wording) One usability question that has been raised with this paper is related to the usage of *lambda-expressions* as non-type template arguments. This question is not handled by our changes to [\[temp.over.link\]](#), since those only impact function templates. Should the following two programs be valid?

```
// foo.h
template <auto> struct foo { };
extern foo<+[] () {}> x;
```

```
// translation unit 1:
#include "foo.h"
```

```
// translation unit 2:
#include "foo.h"
```

and

```
// foo.h
template <auto> struct foo { };
inline foo<+[] () {}> x;
```

```
// translation unit 1:
#include "foo.h"
```

```
// translation unit 2:
#include "foo.h"
```

In both cases, this should be an ODR violation. This is already the effect of the proposed wording, but we propose [adding a note to \[basic.def.odr\]](#) to make this clear.

7. Whether a *lambda-expression* implicitly captures an entity currently depends on whether the

lambda-expression ([**expr.prim.lambda.capture**] 8.1.5.2/7):

- (a) odr-uses the entity (in the case of a variable),
- (b) odr-uses **this** (in the case of the object designated by ***this**), or
- (c) names the entity in a potentially-evaluated expression where the enclosing full-expression depends on a generic lambda parameter declared within the reaching scope of the *lambda-expression*.

Since an unevaluated context does not satisfy the above criteria, there was a question regarding whether variables could be implicitly captured by a *lambda-expression* appearing in an unevaluated context:

```
void f(int i) {  
    auto lambda = [=]{ return i; }; // captures i  
    static_assert(sizeof(L) == sizeof([=]{ return i; })); // Error, i was not captured?  
}
```

The desire is that entities be implicitly captured by *lambda-expressions* even when the lambda appears in an unevaluated context. However, according to the great oracle of C++, Richard Smith, this already works as desired:

Lambdas in unevaluated operands have a lot more value if we also permit default initialization of non-capturing lambdas (that gives us the ability to use `std::set<T, decltype([](T a, T b) { return ... })>`, for instance). If we *do* permit that, then we should treat the body of at least a non-capturing lambda as *not* being an unevaluated operand even when the *lambda-expression* is lexically within one. That's actually already the result that our current definition of "subexpression" gives. And that in turn means that lambdas would need to capture enclosing variables that they use, even in unevaluated operands.

Hence, no wording change is required.

8. Consider the following example:

```
auto f(int i) -> decltype([=](auto g) { return g(i); }) { }
```

As Richard Smith says:

It's not completely clear whether this would be valid: the *lambda-expression* is not lexically within a block scope, but names from the function's block scope are visible at the point of the *lambda-expression*, so is this a local *lambda-expression* or not? If **f** were a non-defining function declaration, I think [**basic.scope.proto**] makes it clear that the lambda would not be a local *lambda-expression* and [**expr.prim.lambda.capture**] 8.1.5.2/3 would disallow it having any captures. It'd be good to clear up exactly what it means for the smallest enclosing scope of a *lambda-expression* to be a block scope; I don't think this mattered up until now.

For the time being, and for the purpose of making this paper progress, we do not tackle this limitation and leave it ill-formed to perform such captures.

9. This paper was proposed before *requires-clauses* were added to the working draft. With *requires-clauses*, the question of whether the following two constructs are valid arises:

```
template<typename T>
void f(T t) requires requires {
    [] () { typename T::invalid foo; };
};
```

and

```
template<typename T>
void f(T t) requires requires {
    [](auto a) { typename decltype(a)::invalid foo; }(t);
};
```

The intent is for both of the above examples to be invalid, just like they would be invalid if that was *SFINAE* during template argument deduction. This is because the body of a lambda is not part of the immediate context for the purpose of template argument deduction. We believe the proposed wording already makes this clear.

3 Proposed Wording

The wording is based on the C++17 DIS [N4659]:

1. In [expr.prim.lambda] 8.1.5/2:

The evaluation of a *lambda-expression* results in a prvalue temporary (12.2). This temporary is called the closure object. ~~A lambda-expression shall not appear in an unevaluated operand (Clause 8), in a template-argument, in an alias-declaration, in a typedef-declaration, or in the declaration of a function or function template outside its function body and default arguments. [Note: The intention is to prevent lambdas from appearing in a signature.—end note]~~ [Note: A closure object behaves like a function object (23.14). — end note]

2. (discussion) In [dcl.typedef] 10.1.3/9:

If the typedef declaration defines an unnamed class (or enum), the first typedef-name declared by the declaration to be that class type (or enum type) is used to denote the class type (or enum type) for linkage purposes only (6.5). [Note: A typedef declaration involving a lambda-expression does not define the associated closure type, and so the closure type is not given a name for linkage purposes.— end note]
[Example:

```
typedef struct { } *ps, S; // S is the class name for linkage purposes
typedef decltype([]{}) C; // the closure type has no name for linkage purposes
```

— end example]

3. (discussion) In [temp.over.link] 17.5.6.1/5:

Two expressions involving template parameters are considered *equivalent* if two function definitions containing the expressions would satisfy the one-definition rule (6.2), except that the tokens used to name the template parameters may differ as long as a token used to name a template parameter in one expression is replaced by another token that names the same template parameter in the other expression. Two *lambda-expressions* are never considered equivalent. [*Note:* The intent is to avoid *lambda-expressions* appearing in the signature of a function template with external linkage. – end note]

Also, add the following example after [temp.over.link] 17.5.6.1/5:

```
// ill-formed, no diagnostic required: the two expressions are
// functionally equivalent but not equivalent
template <int N> void foo(const char (*s)[[]{ }, N]); // TU 1
template <int N> void foo(const char (*s)[[]{ }, N]); // TU 2

// ill-formed, no diagnostic required: the two lambda-expressions are
// functionally equivalent but not equivalent
template <int N> void bar(const char (*s)[[]() { return N; } ]()); // TU 1
template <int N> void bar(const char (*s)[[]() { return N; } ]()); // TU 2

// two different declarations because the non-dependent portions are not
// considered equivalent
template <class T> void baz(T, char (*s)[sizeof(decltype([]{ return 0; } ))]);
template <class T> void baz(T, char (*s)[sizeof(decltype([]{ return 0; } ))]);

// two different declarations because the non-dependent portions are not
// considered equivalent
template <class T> void spam(decltype([]{ }) (*s)[sizeof(T)]);
template <class T> void spam(decltype([]{ }) (*s)[sizeof(T)]);
```

4. (discussion) Add the following paragraph at the end of [temp.alias] 17.5.7:

The type of a lambda expression appearing in an alias template declaration is different between instantiations of that template, even when the lambda expression is not dependent. [*Example:*

```
template <class T>
using A = decltype([] { });
// A<int> and A<char> refer to different closure types
```

– end example]

5. (discussion) Add the following after [temp.deduct] 17.8.2/8 (note that the term *immediate context* is not defined formally in the standard, which is the subject of [CWG1844]):

A lambda expression appearing in a function type or a template parameter is not considered part of the immediate context for the purposes of template argument deduction. [*Note:* The intent is to avoid requiring implementations to deal with substitution failure involving arbitrary statements. [*Example:*


```

template <class T>
auto f(T) -> decltype([]() { T::invalid; } ());
void f(...);
f(0); // error:  invalid expression not part of the immediate context

template <class T, std::size_t = sizeof([]() { T::invalid; })>
void g(T);
void g(...);
g(0); // error:  invalid expression not part of the immediate context

template <class T>
auto h(T) -> decltype([x = T::invalid]() { });
void h(...);
h(0); // error:  invalid expression not part of the immediate context

template <class T>
auto i(T) -> decltype([]() -> typename T::invalid { });
void i(...);
i(0); // error:  invalid expression not part of the immediate context

template <class T>
auto j(T t) -> decltype([](auto x) -> decltype(x.invalid) { } (t));
void j(...);
j(0); // deduction fails on #1, calls #2

```

– end example] – end note]

6. (discussion) Change in [basic.def.odr] 6.2/6:

If the definitions of D satisfy all these requirements, then the behavior is as if there were a single definition of D. [Note: The entity is still declared in multiple translation units, and [basic.link] still applies to these declarations. In particular, *lambda-expressions* ([expr.prim.lambda]) appearing in the type of D may result in the different declarations having distinct types. – end note] If the definitions of D do not satisfy these requirements, then the behavior is undefined.

4 References

- [N4659] Richard Smith, *Working Draft, Standard for Programming Language C++*
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/n4659.pdf>
- [DR1607] Daniel Krügler, *Lambdas in template parameters*
http://www.open-std.org/jtc1/sc22/wg21/docs/cwg_defects.html#1607
- [CWG1844] Richard Smith, *Defining "immediate context"*
http://www.open-std.org/jtc1/sc22/wg21/docs/cwg_active.html#1844