



Improve type generic programming (slides)

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► To cite this version:

| Jens Gustedt. Improve type generic programming (slides). 2021. hal-03165732v1

HAL Id: hal-03165732

<https://inria.hal.science/hal-03165732v1>

Preprint submitted on 10 Mar 2021 (v1), last revised 2 Feb 2022 (v2)

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Improve type generic programming

ISO/IEC JTC 1/SC 22/WG14 **N2638**

WG21 **P2304**

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Example

"Five" point tangent evaluation for approximation of a derivative:

$$(-\text{func}(x+2*h) + 8*\text{func}(x+h) - 8*\text{func}(x-h) + \text{func}(x-2*h)) / (12*h)$$

With a macro?

```
// WARNING: multiple argument evaluation
#define TANGENT5(FUNC, X, H) \
    (- FUNC((X)+2*(H)) + 8*FUNC((X)+ (H)) \
    - 8*FUNC((X)- (H)) + FUNC((X)-2*(H))) / (12*(H))
```

How to create an interface that is simple and safe to use?

With a lambda:

```
auto const λ5 = [] (double x, double h, double (*func) (double)) {
    return (-func(x+2*h)+8*func(x+h)-8*func(x-h)+func(x-2*h)) / (12*h);
};
// Can be used in function call or for a function pointer
double (*fp) (double, double, double (*) (double)) = λ5;
```

Example

or so:

```
// freeze  $\varepsilon$  to  $\delta$  and have the function parameter dependent
auto const  $\lambda 5\varepsilon = [\delta = \varepsilon] (\text{double } x, \text{typeof}(x) \text{ func}(\text{typeof}(x))) \{$ 
    double h =  $\delta * x$ ;
    return (-func(x+2*h)+8*func(x+h)-8*func(x-h)+func(x-2*h)) / (12*h);
};
```

or so:

```
// also freeze a function, and have the parameter dependent
auto const  $\lambda 5\varepsilon\_func = [\delta = \varepsilon, func = f] (\text{typeof}(func(0)) x) \{$ 
    auto h =  $\varepsilon * x$ ;
    return (-func(x+2*h)+8*func(x+h)-8*func(x-h)+func(x-2*h)) / (12*h);
};
```



Policy

- *extend* the standard
 - valid code remains valid
 - new feature integrates syntactically and semantically
- fix as much requirements as possible through constraints
 - specific syntax
 - explicit constraints
- avoid new undefined behavior
 - only, if property is not (or hardly) detectable at translation time
 - or we leave design space to implementations
- don't mess with ABI
 - no changes
 - no extensions



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A leveled specification: type inference

Type inference from identifiers, value expressions and type expressions

See JeanHeyd's paper [N2619](#) on `typeof`

- keep qualifiers and `_Atomic`

[N2674](#) Type inference for variable definitions and function return
`auto` feature

- type is inferred from initializer or `return`
- conversion: lvalue, array-to-pointer, function-to-pointer
- lose qualifiers and `_Atomic`



A leveled specification: lambdas

N2675 Simple lambdas: function literals and value closures

- primary use: function call expressions
- local variables are captured explicitly and by value
- conversion: no captures => function pointer

N2634 Type-generic lambdas

- **auto** parameters, types are inferred from
 - function call
 - function pointer conversion

N2635 Lvalue closures

- lvalue capture: named alias for local variable (pseudo-references)



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Existing type-generic features in C

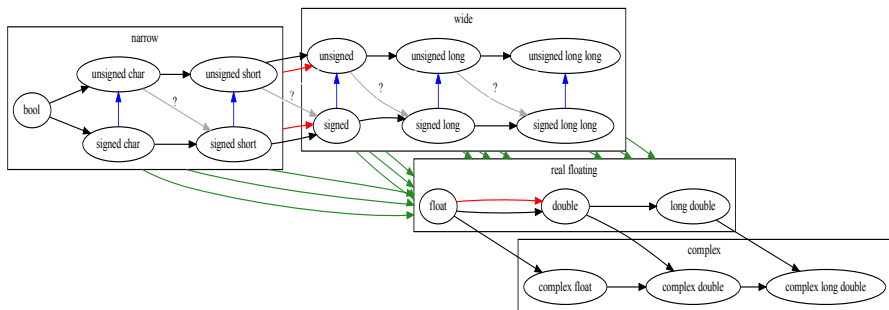
- operators
- promotions and conversions
- macros
- variadic functions
- function pointers
- **void** pointers
- type-generic C library functions
- **_Generic** primary expressions



Operators

- most binary operators, have the same type for both operands
- bit-wise operators are defined for
 - wide integer types
- additionally for multiplicative operators
 - real floating point types
 - complex types
- additionally for additive operators
 - object pointers

promotions and conversions



- implicit conversion
- promotion and default argument conversion
- default arithmetic conversion

Macros

- Macros for type-generic expressions (see intro above)
 - no local variables
 - dangerous because of multiple evaluation of arguments
- Macros placeable as statements
 - weird conventions, usually

<code>/* Macro */</code>		<code>/* Type-generic lambda */</code>	
<code>#define myfeature(X)</code>	<code>\</code>	<code>#define myfeature</code>	<code>\</code>
<code>do {</code>	<code>\</code>	<code>[] (auto x) {</code>	<code>\</code>
<code> typeGuess x = (X);</code>	<code>\</code>	<code> /* do something with x */</code>	<code>\</code>
<code> /* do something with x */</code>	<code>\</code>	<code>}</code>	
<code>} while(false)</code>			
<code>/* Macro usage, conversion? */</code>		<code>/* Lambda usage, type safe */</code>	
<code>myfeature(42);</code>		<code>myfeature(42);</code>	

- Macros for declarations and definitions



Type oblivion

the user has all the burden

- Variadic functions
 - weird default conversions
 - weird library support (`va_list` a reference type?)
 - intrinsically unsafe
 - rarely used for new code
- `void*` pointers
 - unhuman effort has to be made to keep all the types correct
 - not even used by variadic functions
- function pointers
 - used with `void*` parameters for type-genericity (`bsearch`, `qsort`)



Automatic type deduction

- type-generic C library functions
 - `<tgmath.h>`
 - `<stdatomic.h>`
- **_Generic** primary expressions
 - difficult to extend
 - mostly restricted to function-like macros
 - not widely used



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Missing features

- temporary variables
 - temporary objects with a name
- controlled encapsulation
 - don't steal information from the surrounding scopes
 - don't pollute the surrounding scopes
- controlled constant propagation
 - control exactly what information is considered constant



Missing features

- automatic instantiation of function pointers
 - missing for `<tgmath.h>`
- automatic instantiation of specializations
 - works well with controlled constant propagation
- direct type inference
 - avoid guessing or forcing a type
 - avoid implicit conversions



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Type inference

in C implementations and in other related programming languages

- **auto** type inference (`__auto_type__`)
- the **typeof** feature
- the **decltype** feature



Identifiers of surrounding scopes

use of identifiers distinguishes

- visibility by scope
- access
 - no linkage (same function, relative addressing)
 - internal linkage (same TU, global addressing)
 - external linkage (same program, linktime resolution)



Identifiers of surrounding scopes

What does an identifier mean in a local function?

- local function, short lifetime, multiple instances
 - when is the definition evaluated?
- when is an outer identifier evaluated?
 - evaluation of function definition or lambda expression
 - function call
- how much evaluation?
 - remains lvalue
 - lvalue conversion
 - promotion

Lambdas: design space and terminology

The design space for captures and closures

access to automatic variables

- evaluate when seeing lambda, *value capture*
 - rvalue (no address)
 - unmutable value (**const** qualified, addressable)
 - mutable value (C++ keyword `mutable`)
- evaluate when calling lambda
 - *lvalue capture*

Terminology

- | | |
|---------------------------|---|
| • <i>function literal</i> | $\Leftrightarrow$ anonymous function, no captures |
| • <i>closure</i> | $\Leftrightarrow$ any capture |
| • <i>value closure</i> | $\Leftrightarrow$ only value captures |
| • <i>lvalue closure</i> | $\Leftrightarrow$ at least one lvalue capture |

Lambdas: existing extensions

- Objective C's blocks
 - value capture per default
 - managed memory for lvalue captures
- Statement expressions
 - weird specification of the effective value
 - all captures are lvalue captures
- Nested functions
 - all captures are lvalue captures
 - separation of definition and call
- C++ lambdas
 - capture model chosen by user
 - [un]mutable value captures
 - lvalue captures

