Improve type generic programming (slides)
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Improve type generic programming
ISO/IEC JTC 1/SC 22/WG14 N2890
WG21 P2304

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https://gustedt.gitlabpages.inria.fr/modern-c/
1. Introduction

2. A leveled specification

3. Existing type-generic features in C

4. Missing features

5. Design choices

6. Common extensions
"Five" point tangent evaluation for approximation of a derivative:

\[
(-\text{func}(x+2\cdot h) + 8 \cdot \text{func}(x+h) - 8 \cdot \text{func}(x-h) + \text{func}(x-2\cdot h))/(12\cdot h)
\]

With a macro?

```c
// 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:

```cpp
auto const \( \lambda_5 \) = [](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)) = \( \lambda_5 \);
```
Introduction

Example

or so:

```c
// freeze ε to δ and have the function parameter dependent
auto const λ5ε = [δ = ε](double x, typeof(x) func(typeof(x))) {
    double h = δ * x;
    return (-func(x+2*h)+8*func(x+h)-8*func(x-h)+func(x-2*h))/(12*h);
};
```

or so:

```c
// also freeze a function, and have the parameter dependent
auto const λ5ε_func = [δ = ε, func = f](typeof(func(0)) x) {
    auto h = ε * 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 N2899 on typeof

- **typeof**: keep qualifiers and \_Atomic
- **remove_quals**: remove qualifiers

N2891 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
- as-if **auto** were replaced by a typeof expression
- no new types in an **auto** declaration!
## A leveled specification: lambdas

### N2892 Basic lambdas for C
- primary use: function call expressions
- no default captures, all captures are explicit
- local *identifiers* are captured by `& id` notation
- *values* are captured by `id = expr`
- modest syntax ambiguity
- conversion: no captures → function pointer

### N2893 Options for lambdas
- `&` for default identifier captures - migration path for gcc
- `=` for default *shadow* captures - clang
- `id` for explicit shadow captures
- more syntax ambiguity
A leveled specification: usage patterns for lambdas

### N2894 Type-generic lambdas

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

### N2862 Function Pointer Types for Pairing Code and Data

Lead by Martin Uecker

- main feature is independent of lambdas:
  - provide API for existing ABI
    - additional context pointer to function calls
  - option to integrate lambdas

### N2895 A simple defer feature for C

- use lambdas as syntax to describe **defer**
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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
Existing type-generic features in C

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

```c
/* Macro */
#define myfeature(X) 
#define myfeature 
do {
    typeGuess x = (X);
    /* do something with x */
} while(false)

/* Type-generic lambda */
#define myfeature [ ] (auto x) {
    /* do something with x */
}

/* Macro usage, conversion? */
myfeature(42);

/* Lambda usage, type safe */
myfeature(42);
```

- Macros for declarations and definitions
Type oblivion

- 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`)

the user has all the burden
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
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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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 *expression* when seeing lambda, *value capture*
  - rvalue (no address)
  - immutable value (*const* qualified, addressable)
  - mutable value (C++ keyword *mutable*)
- evaluate *variable* when seeing lambda, *shadow capture*
  - same possible differentiation as above
- evaluate when calling lambda
  - *identifier capture*

Terminology

- *function literal* <=> anonymous function, no captures
- *closure* <=> any capture
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in C implementations and in other related programming languages

- auto type inference (__auto_type__)  
- the typeof feature  
- the decltype feature
**Lambdas: existing extensions**

- **Objective C’s blocks**
  - shadow capture per default
  - managed memory for identifier captures

- **Statement expressions**
  - weird specification of the effective value
  - all captures are identifier captures

- **Nested functions**
  - all captures are identifier captures
  - separation of definition and call

- **C++ lambdas**
  - capture model chosen by user
    - [un]mutable value or shadow captures
    - identifier and alias captures
    - defaults & and =