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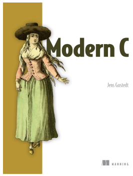
https://gustedt.gitlabpages.inria.fr/modern-c/



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Example

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

```
(-func(x+2*h) + 8*func(x+h) - 8*func(x-h) + 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 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:

```
// 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 $\longrightarrow$ funtion 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 patters 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 indepedent 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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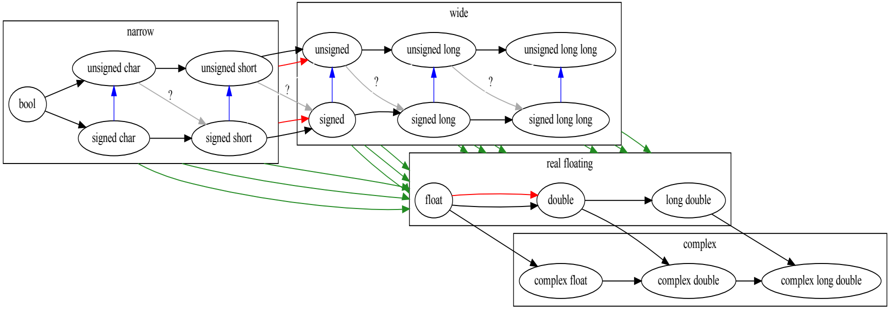
Existing type-generic features in C

- 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

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)                 \
do {                                 \
   typeGuess x = (X);                \
   /* do something with x */         \
} while(false)

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

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

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

- 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?)
  - intrinsicly 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 inferrence
    - 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 evalutated?
- when is an outer identifier evalutated?
  - 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)
  - unmutable 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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Type inferrence

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 — clang
  - shadow capture per default
  - managed memory for identifier captures
- Statement expressions — gcc, clang, intel, ibm xl, open64
  - weird specification of the effective value
  - all captures are identifier captures
- Nested functions — gcc
  - all captures are identifier captures
  - separation of definition and call
- C++ lambdas — since C++11
  - capture model chosen by user
    - [un]mutable value or shadow captures
    - identifier and *alias* captures
    - defaults & and =