

Bit fields and inline functions

Microcontrollers

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Bit fields in C

Programming networking protocols or close to hardware often requires us to interpret data bit-wise rather than byte-wise.

- ▶ For instance, the IPv4 header starts with 4 bits for the version, 4 bits of the header length, 6 bits ToS, and so on. Another example is the SREG register of the ATmega32.
- ▶ The C and C++ programming languages defines so-called **bit fields** to model such data layouts as a sequence of bits. [cppref-c-bitfields]
- ▶ Syntactically, a bit field is a struct¹ member of integer type plus a declaration of how many bits are spent.

```
1 typedef struct {  
2     unsigned int version : 4;  
3     unsigned int ihl : 4;  
4     unsigned int tos : 6;  
5     /* and more */  
6 } ipv4_header;
```

¹ Actually, also union members can be defined as bit fields.

Bit fields in C

- ▶ Adjacent bit fields are *usually* packaged together, but it is **implementation-defined**.
- ▶ If field size is larger than type then value is limited to type's size or a compiler error is raised.

```
1 typedef struct {  
2     unsigned int a : 4;  
3     unsigned int : 1;    /* Nameless field for padding. */  
4     unsigned int b : 2;  
5     unsigned int : 0;    /* Padding to next allocation unit boundary. */  
6 } mybitfield;
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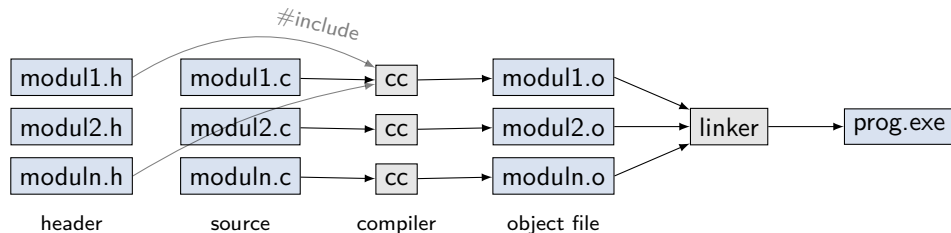
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Technical details:

- ▶ A signed field means two's complement. A signed field of size 1 can only have values 0 and -1.
- ▶ The standard defines `int`, `signed int`, `unsigned int`, `_Bool` as base types, but implementations may support additional types, such as `char`, `short`, `long` and its signed and unsigned counterparts.
- ▶ It is implementation-defined whether `int` is signed or unsigned. For bit fields `int` has different meaning than `signed int`!

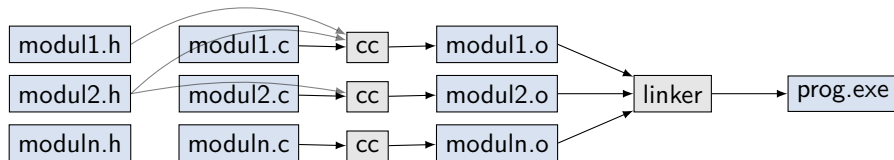
Translation units and linking

- ▶ A **translation unit** is (typically) a `.c` file that is compiled to an object file.
- ▶ The object files are then linked to a final binary (executable, library, ATmega32 program, ...)



Functions and symbols

- ▶ A function definition exports a **symbol**.
 - ▶ If other translation units call this function then the linker looks for this symbol.
 - ▶ The function **declaration** in the header file determines the symbol name.
 - ▶ No two translation units can export the same symbol!



Example: Implement a function `f()`

- ▶ Say, `modul2.h` declares it and `modul2.c` defines it.
- ▶ Only `modul2.o` has the symbol for `f()`.
- ▶ But we could call it in `modul1.c`, by including `modul2.h` and therefore knowing its symbol name.

Inline functions

With C99 we can give the compiler a *hint* to inline a function [cppref-c-inline]:

- ▶ When calling a function, instead placing a function call the function's body is placed.
- ▶ Inline functions are like macros, but with types.
- ▶ For small functions this is an optimization technique to save the function call costs. However, it is only a hint to the compiler, we cannot force it.

Dilemma

- ▶ Where to **define** the inline function?
- ▶ Definition (now only declaration) must be known **for all translation units** for inlining.
→ Definition in header file.
- ▶ But **only one** translation unit must export a symbol.

Answer: Declare the inline function with **extern** keyword in **one** translation unit (.c file).

Complete inline function demo

The header file `geom.h`:

```
1 #ifndef geom_h_Epai3ohkaevei0ea
2 #define geom_h_Epai3ohkaevei0ea
3
4 #include <math.h>
5
6 inline double sq(double x) {
7     return x * x;
8 }
9
10 inline double norm(double x, double y) {
11     return sqrt(sq(x) + sq(y));
12 }
13
14 #endif
```

The implementation file `geom.c`:

```
1 #include "geom.h"
2
3 extern inline double sq(double x);
4 extern inline double norm(double x, double y);
```


Static and inline functions

- ▶ If you declare a function as `static` then it is only local to this translation unit.
 - ▶ No symbol is exported. The namespace is not polluted.
 - ▶ The function cannot be called from another translation unit.
- ▶ The definition of an inline function does not automatically export a symbol.
 - ▶ So `inline` is a bit like `static`, but in header files.
 - ▶ However, an external definition *must* exist. Hence, we have to explicitly add an export definition of the function in *one* translation unit using the `extern` keyword.

References I

[cppref-c-bitfields] *cppreference.com: bit fields*. URL:
https://en.cppreference.com/w/c/language/bit_field.

[cppref-c-inline] *cppreference.com: inline function specifier*. URL:
<https://en.cppreference.com/w/c/language/inline>.