

# C Macros, const , volatile and inline

Lecture 7

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# C Preprocessor

*The **C preprocessor** is a **macro processor** that is used **automatically** by the C compiler to transform your program **before** compilation.*

GNU documentation



# Macro Examples

```
#ifdef _DEBUG
#define GL_CHECK(stmt) do { \
    stmt; \
    CheckOpenGLError(#stmt, __FILE__, __LINE__); \
} while (0)
#else
#define GL_CHECK(stmt) stmt
#endif
```

Stackoverflow.com

## cl.h

```
/* Error Codes */
#define CL_SUCCESS 0
#define CL_DEVICE_NOT_FOUND -1
#define CL_DEVICE_NOT_AVAILABLE -2
#define CL_COMPILER_NOT_AVAILABLE -3
#define CL_MEM_OBJECT_ALLOCATION_FAILURE -4
...
```

OpenCL

```
#define ARRAY_SIZE(a) (sizeof(a) / sizeof(*a))
```

Stackoverflow.com



# C Preprocessor Directives

The list below includes some of the directives supported by the C preprocessor:

- `#define`
- `#undef`
- `#include`
- `#ifdef ... #else ... #endif`
- `#ifndef ... #else ... #endif`
- among others.



# #include

- Inserts the contents of an **external** file into **current source** code at the point where **#include** is invoked.
- Example

**maininclude.c**

```
#include "stdio.h"
```

```
int main( void )  
{  
    printf("Hellow world!\n");  
  
    return 0;  
}
```

Includes the contents of **stdio.h** header file into the **maininclude.c** source code.

Take a look at the effects of the **#include** above with:

```
~$ gcc -std=c99 -E maininclude.c > maininclude.i
```



# #define

- Create macros.
  - **#define** is followed by the name of the macro and the token sequence it should be an abbreviation for.
- Example

Macro defined with  
**#define** preprocessing directive

**maindefine.c**

```
#define VALUE 99

int main( void ) {
    int x;

    x = VALUE;

    return x;
}
```

Macro defined as a GCC  
command line argument

~\$ gcc -D VALUE=99 ...

**maindefine.c**

```
int main( void ) {
    int x;

    x = VALUE;

    return x;
}
```



# #ifdef ... #else ... #endif

Allows the compiler to conditionally remove lines of code based on the existence (or not) of a macro.

Macro defined with  
#define preprocessing directive

**mainifdef.c**

```
#define VALUE 99

int main( void ) {
    int x;

#ifdef VALUE
    x = VALUE;
#else
    x = 255;
#endif

    return x;
}
```

Macro defined as a GCC  
command line argument

~\$ gcc -D VALUE=99 ...

**mainifdef.c**

```
int main( void ) {
    int x;

#ifdef VALUE
    x = VALUE;
#else
    x = 255;
#endif

    return x;
}
```



# Include Guards

Suppose the following C program:

**maintriangle.c**

```
struct Vertex {  
    float position[3];  
    float normal[3];  
};
```

```
struct Triangle {  
    struct Vertex vertices[3];  
};
```

```
int main( void ) {  
    struct Vertex v;  
  
    struct Triangle t;  
  
    return v.position[0] + t.vertices[0].position[0];  
}
```

**vertex.h**

```
struct Vertex {  
    float position[3];  
    float normal[3];  
};
```

**triangle.h**

```
#include "vertex.h"  
  
struct Triangle {  
    struct Vertex vertices[3];  
};
```

**main.c**

```
#include "vertex.h"  
#include "triangle.h"  
  
int main( void ) {  
    struct Vertex v;  
  
    struct Triangle t;  
  
    return ...  
}
```

Type definition.





# Include Guards

## vertex.h

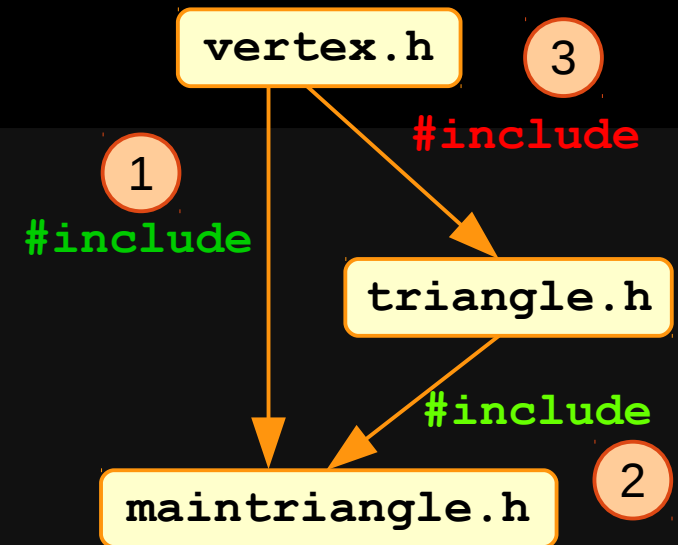
```
struct Vertex {  
    float position[3];  
    float normal[3];  
};
```

## maintriangle.c

```
#include "vertex.h"  
#include "triangle.h"  
  
int main( void ) {  
    struct Vertex v;  
  
    struct Triangle t;  
  
    return ...  
}
```

## triangle.h

```
#include "vertex.h"  
  
struct Triangle {  
    struct Vertex vertices[3];  
};
```



## Let's build maintriangle:

```
~$ gcc -Wall -Werror -std=c99 -E main.c > main.i  
~$ gcc -Wall -Werror -std=c99 -S main.i  
In file included from triangle.h:1:0,  
    from main.c:2:  
vertex.h:4:8: error: redefinition of 'struct Vertex'  
    struct Vertex {  
        ^  
In file included from main.c:1:0:  
vertex.h:4:8: note: originally defined here  
    struct Vertex {  
        ^
```

How to solve that?



# Include Guards

vertex.h (old)

```
struct Vertex {  
    float position[3];  
    float normal[3];  
};
```

vertex.h (new)

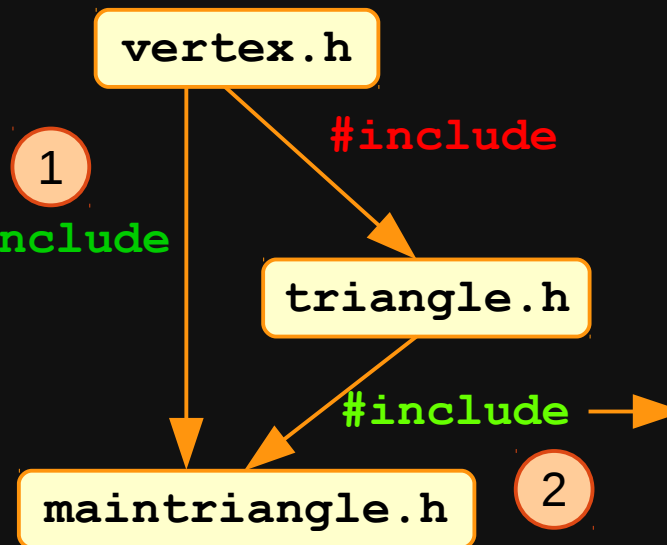
```
#ifndef VERTEX_H_  
#define VERTEX_H_  
  
struct Vertex {  
    float position[3];  
    float normal[3];  
};  
  
#endif // VERTEX_H_
```

Include guards!

Guarded code  
Block (it won't  
be included twice)!

Every header should be  
guarded with inc. guards  
(even triangle.h)!

maintriangle.c will  
#include vertex.h.  
As vertex.h is read into  
maintriangle.c, its  
preprocessing directives  
are executed and (since  
it was not previously  
defined) the macro  
VERTEX\_H\_ is first  
defined.



As soon as triangle.h  
starts to be read into  
maintriangle.c, it  
#include vertex.h.  
The preprocessor will thus  
start reading vertex.h into  
triangle.h. As soon as it  
finds the preprocessor  
directive #ifndef, it ignores  
the contents of the  
conditional block until  
#endif.



# Function-like Macros

It is a macro whose name is followed by parentheses.

- These macros can take arguments!

**mainmacro.c**

```
#define OFFSET_VALUE 10
#define OFFSET_FUNCTION( val ) val + OFFSET_VALUE

int main( int argc, char *argv[] )
{
    int x;

    if ( argc > 1)
        x = 2;
    else
        x = 1;

    int y = OFFSET_FUNCTION( x );

    return y;
}
```

Creates a function-like macro called `OFFSET_FUNCTION` which takes `val` as argument.



# Macro Pitfalls

## mainmacro.c

```
#define OFFSET_VALUE 10

#define OFFSET_FUNCTION( val ) val + OFFSET_VALUE

int main( int argc, char *argv[] )
{
    int x;

    if ( argc > 1)
        x = 2;
    else
        x = 1;

    int y = 3 * OFFSET_FUNCTION( x );

    return y;
}
```

3 \* the result of  
**OFFSET\_FUNCTION**

According to the code above, the value of **OFFSET\_FUNCTION** is multiplied by 3. However, the **actual result is different. Why?**

## mainmacro.i

```
# 1 "mainmacros.c"
# 1 "<built-in>"
# 1 "<command-line>"
# 1 "/usr/include/stdc-predef.h" 1 3 4
# 1 "<command-line>" 2
# 1 "mainmacros.c"

int main( int argc, char *argv[] )
{
    int x;

    if ( argc > 1)
        x = 2;
    else
        x = 1;

    int y = 3 * x + 10;

    return y;
}
```



```
~$ gcc -Wall -Werror -pedantic -std=c99 -O0 -E mainmacros.c > mainmacros.i
```



# A Solution for this Problem Instance

**mainmacro.c (old)**

```
#define OFFSET_VALUE 10
#define OFFSET_FUNCTION( val ) val + OFFSET_VALUE
int main( int argc, char *argv[] )
{
    ...
}
```

**mainmacro.c (new)**

```
#define OFFSET_VALUE 10
#define OFFSET_FUNCTION( val ) ( val + OFFSET_VALUE )
int main( int argc, char *argv[] )
{
    ...
}
```

```
~$ gcc -Wall -Werror -pedantic -std=c99 -O0 -E mainmacro.c > mainmacro.i
```

**mainmacro.i**

```
...
int main( int argc, char *argv[] )
{
    int x;

    ...

    int y = 3 * ( x + 10 );
    return y;
}
```

Now the expression  
will be correctly evaluated!



# const type Qualifier

**const** indicates to the compiler that the **content** of the qualified object **will not** be changed.

- The value of a **const** variable can be eventually changed, but not by the current program.
  - Sometimes it is said that **const** variables would be more accurately described as **read-only** variables (more on that later)!



# const Variable

## mainconst1.c

```
int i = 10;

int main( void )
{
    return i;
}
```

If the value of `i` is not going to be modified along the program, we can declare it as `const`.

## mainconst2.c

```
const int ci = 20;

int main( void )
{
    ci = 30;

    int i = ci;
    return i + ci;
}
```

`const` variables must be initialized!

Any attempt to modify the value of `ci` will make the compiler raise an error.

In an attribution, the `const` value can be freely copied into other non-`const` variables.



# Pointer to const

## mainconst3.c

```
int i = 10;
const int ci = 20;
const int *pci; ✓
int *pi;
int main( void )
{
    pci = &i; ✓
    pci = &ci; ✓
    pci = pi; ✓
    pi = pci; ✗
    return ...
}
```

The value of the pointed variable cannot be modified through the pointer.



**const int ci**  
or **int const ci**

**const int \*pci**  
or **int const \*pci**

**int \*pi**

**int i**

100	10
...	
200	20
...	
300	????
...	
400	????

May contain only the address of a non-const variable.

Might contain the address of a const or non-const variable.





# const Pointer

## mainconst4.c

```
int i = 10;

const int ci = 20;

const int *pci;

int *pi;

int main( void )
{
    int *const cpi; ❌
    int *const cpi = &i; ✅
    int *const cpi = &ci; ❌
    int *const cpi = pi; ✅
    int *const cpi = pci; ❌
    return ...
}
```

int i	100	10
...	...	...
const int ci	200	20
...	...	...
const int *pci	300	????
...	...	...
int *pi	400	????
...	...	...
int *const cpi	500	????

The value of the pointer cannot be modified to point to something else.

May contain only the address of a non-const variable.



# const Pointer to const

mainconst5.c

```
int i = 10;
const int ci = 20;
const int *pci;
int *pi;

int main( void )
{
    const int *const cpci;  

    const int *const cpci = &i;  

    const int *const cpci = &ci;  

    const int *const cpci = pci;  

    const int *const cpci = pi;  

    return ...  

}
```

**const int \*const cpci**

**int i**

**const int ci**

**const int \*pci**

**int \*pi**

100	10
...	
200	20
...	
300	????
...	
400	????
...	
500	????

May contain the  
address of const and  
non-const variable.



# const vs. Function Parameters

mainfconst1.c

```
int f_i( int a )
{
    return a;
}
...
```

a is a int  
parameter  
passed by  
value.

f () receives copies of the  
integer arguments.

f () receives copies of the  
integer values that are being  
pointed. Thus, **it does not  
matter if the pointed value is  
const because the function  
can only alter its copy!**

mainfconst1.c

```
...
int i = 10;
const int ci = 20;
int *pi;
const int *pci;

int main( void )
{
    int *const cpi = &i;
    const int *const cpci = &i;

    i = f_i( i );
    i = f_i( ci );
    i = f_i( *pi );
    i = f_i( *cpi );
    i = f_i( *pci );
    i = f_i( *cpci );
    ...
}
```



# const vs. Function Parameters

mainfconst2.c

```
int f_ci( const int a )
{
    return a;
}
...
```

a is a const int  
parameter passed  
by value.

f () receives copies of the  
integer arguments. **The copy  
will be treated as const  
within f ()**.

f () receives copies of the  
integer values that are being  
pointed. The parameter will  
be treated as const within  
the function.

mainfconst2.c

```
...
int i = 10;
const int ci = 20;
int *pi;
const int *pci;

int main( void )
{
    int *const cpi = &i;
    const int *const cpci = &i;

    i = f_ci( i ); ✓
    ci = f_ci( ci ); ✓
    i = f_ci( *pi ); ✓
    i = f_ci( *cpi ); ✓
    i = f_ci( *pci ); ✓
    i = f_ci( *cpci ); ✓
    ...
}
```



# const vs. Function Parameters

mainfconst3.c

```
int f_pi( int *a )
{
    return (*a);
}
...
```

→ a is a pointer  
to int.

f () receives copies of the  
addresses of the integers  
that are being pointed.

If, through the pointer, a  
const value is going to be  
reinterpreted as non-const,  
the compiler raises an error.

mainfconst3.c

```
...
int i = 10;
const int ci = 20;
int *pi;
const int *pci;

int main( void )
{
    int *const cpi = &i;
    const int *const cpci = &i;

    i = f_pi( pi ); ✓
    i = f_pi( cpi ); ✓
    i = f_pi( pci ); ✗
    i = f_pi( cpci ); ✗
    ...
}
```



# const vs. Function Parameters

mainfconst4.c

```
int f_pci( const int *a )
{
    return (*a);
}
...
```

→ a is a pointer  
to a const int.

**Pointer to const  
parameter prevents  
the modification  
of the pointed value.**

f() receives copies of the  
addresses of the integers  
that are being pointed.

**There won't be any problem  
if, through the pointer, a  
non-const value is  
reinterpreted as const.**

mainfconst4.c

```
...
int i = 10;
const int ci = 20;
int *pi;
const int *pci;

int main( void )
{
    int *const cpi = &i;
    const int *const cpci = &i;

    i = f_pci( pi ); ✓
    i = f_pci( cpi ); ✓
    i = f_pci( pci ); ✓
    i = f_pci( cpci ); ✓
    ...
}
```



# const vs. Function Parameters

mainconst5.c

```
int f_cpi( int *const a )
{
    return (*a);
}
...
```

→ a is a const pointer  
to an int.

Why to pass a **const** pointer if **f()** will receive a copy of it (i.e. there is no risk of **f()** altering the original pointer)?

Restrictions via syntax is also an argument for the use of **const**.

**f()** receives copies of the addresses of the integers that are being pointed.

The copy of the pointer will be **const** within **f()**.

Through the pointer, the pointed value will be interpreted as non-const!

mainconst5.c

```
...
int i = 10;
const int ci = 20;
int *pi;
const int *pci;

int main( void )
{
    int *const cpi = &i;
    const int *const cpci = &i;

    i = f_cpi( pi ); ✓
    i = f_cpi( cpi ); ✓
    i = f_cpi( pci ); ✗
    i = f_cpi( cpci ); ✗
    ...
}
```



# const vs. Function Parameters

mainfconst6.c

```
int f_cpci( const int *const a )
{
    return (*a);
}
...
```

**a is a  
const pointer  
to a const int.**

**f () receives copies of the  
addresses of the integers  
that are being pointed.**

**The copy of the pointer  
will be const within f ().**

**Through the pointer, the  
pointed value will be  
Interpreted as const!**

mainfconst6.c

```
...
int i = 10;
const int ci = 20;
int *pi;
const int *pci;

int main( void )
{
    int *const cpi = &i;
    const int *const cpci = &i;

    i = f_cpci( pi );
    i = f_cpci( cpi );
    i = f_cpci( pci );
    i = f_cpci( cpci );
    ...
}
```





# volatile type Qualifier

*An object that has **volatile-qualified type** may be **modified** in ways **unknown** to the **implementation** or have other unknown side effects.*

C99 Spec.



# volatile type Qualifier

- Example (from the C99 Spec.):

```
extern const volatile int real_time_clock;
```

- A good text about **volatile**:
  - How to Use C's **volatile** Keyword, by Nigel Jones.
    - <http://www.barrgroup.com/Embedded-Systems/How-To/C-Volatile-Keyword>



# Reducing the Cost of Function Calls

## inline1.c

```
int F1( int a )
{
    return a + 1;
}

int main( int argc, char *argv[] )
{
    int x;

    if ( argc > 1 )
        x = 2;
    else
        x = 1;

    x = F1( x );

    return x;
}
```

## inline1.s

```
.file "main.c"
.text
.globl F1
.type F1, @function

F1:
    pushq    %rbp
    movq %rsp, %rbp
    movl %edi, -4(%rbp)
    movl -4(%rbp), %eax
    addl $1, %eax
    popq %rbp
    ret

...

main:
    ...
    call F1
    ...
    ret
    ...
```

Optimization OFF!

```
~$ gcc -Wall -Werror -pedantic -O0 -std=c99 -E inline1.c > inline1.i
~$ gcc -Wall -Werror -pedantic -O0 -std=c99 -fno-asynchronous-unwind-tables -S inline1.i
```



# Reducing the Cost of Function Calls

## inline1.c

```
int F1( int a )
{
    return a + 1;
}

int main( int argc, char *argv[] )
{
    int x;

    if ( argc > 1 )
        x = 2;
    else
        x = 1;

    x = F1( x );

    return x;
}
```

The compiler  
itself may  
decide to  
inline some  
functions!

## inline1.s

```
.file "main.c"
.text
.p2align 4,,15
.globl F1
.type F1, @function
F1:
    leal 1(%rdi), %eax
    ret
.size F1, .-F1
.section .text.startup,"ax",@progbits
.p2align 4,,15
.globl main
.type main, @function
main:
    xorl %eax, %eax
    cmpl $2, %edi
    setge %al
    addl $2, %eax
    ret
```

No function call!  
F1 () was inlined!

Optimization ON!

```
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -E inline1.c > inline1.i
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -fno-asynchronous-unwind-tables -S inline1.i
```



# Reducing the Cost of Function Calls

## inline2.c

```
void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[ j + 1 ] = v[j];
            j = j - 1;
        }
        v[ j + 1 ] = key;
    }
}
```

```
int y[5] = { 5, 4, 3, 2, 1 };
```

```
int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```

## inline2.s

```
...
.globl    InsertionSort
.type    InsertionSort, @function
InsertionSort:
    pushq    %rbp
    movq    %rsp, %rbp
    ...
    ret
.size    InsertionSort, .-InsertionSort
.globl    y
.data
.align 16
.type    y, @object
.size    y, 20
y:
    .long    5
    ...
main:
    ...
    call InsertionSort
    ...
    ret
    ...
```

Optimization OFF!

```
~$ gcc -Wall -Werror -pedantic -O0 -std=c99 -E inline2.c > inline2.i
~$ gcc -Wall -Werror -pedantic -O0 -std=c99 -fno-asynchronous-unwind-tables -S inline2.i
```



# Reducing the Cost of Function Calls

## inline2.c

```
void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[j + 1] = v[j];
            j = j - 1;
        }
        v[j + 1] = key;
    }
}
```

```
int y[5] = { 5, 4, 3, 2, 1 };
```

```
int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```

In this case, the  
function call **was**  
**not optimized** by  
the compiler.

## inline2.s

```
...
.globl    InsertionSort
.type    InsertionSort, @function
InsertionSort:
    cmpl $1, %esi
    jle .L1
    ...
    rep ret
...
.size    InsertionSort, .-InsertionSort
.section .text.startup,"ax",@progbits
.p2align 4,,15
.globl    main
.type    main, @function
main:
    ...
    call InsertionSort
    ...
    ret
    ...
```

**Function  
call!**

How do we **ask** the  
compiler to **inline**  
functions?

**Optimization ON!**

```
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -E inline2.c > inline2.i
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -fno-asynchronous-unwind-tables -S inline2.i
```



# **inline** Function Specifier

*A function declared with an inline function specifier is an inline function. (...) Making a function an inline function suggests that calls to the function be as fast as possible. The extent to which such suggestions are effective is implementation-defined.*

C99 Spec



# Simple inline Example

## inline2.c

```
inline void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[j + 1] = v[j];
            j = j - 1;
        }
        v[j + 1] = key;
    }
}

int y[5] = { 5, 4, 3, 2, 1 };

int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```

## inline2.s

```
.file      "main.c"
.section   .text.startup,"ax",@progbits
.p2align   4,,15
.globl     main
.type      main, @function
```

```
main:
---
    xorl    %esi, %esi
.L6:
    movl    y+4(,%rsi,4), %ecx
    ...
    movl    y(%rip), %eax
    ret
---
```

**No function call!  
F1 () was inlined!**

**Optimization ON!**

```
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -E inline2.c > inline2.i
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -fno-asynchronous-unwind-tables -S inline2.i
```





# Splitting the Code

## inline2.c

```
inline void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[j + 1] = v[j];
            j = j - 1;
        }
        v[j + 1] = key;
    }
}
```

```
int y[5] = { 5, 4, 3, 2, 1 };

int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```

## insertion.c

```
inline void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[j + 1] = v[j];
            j = j - 1;
        }
        v[j + 1] = key;
    }
}
```

**Add declaration!**

## inline3.c

```
inline void InsertionSort( int *v, int size );

int y[5] = { 5, 4, 3, 2, 1 };

int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```



# Splitting the Code

## insertion.c

```
inline void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[j + 1] = v[j];
            j = j - 1;
        }
        v[j + 1] = key;
    }
}
```

## inline3.c

```
inline void InsertionSort( int *v, int size );

int y[5] = { 5, 4, 3, 2, 1 };

int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```

```
-Wall -Werror -pedantic -O2 -std=c99
```

```
~$ gcc ... -E insertion.c > insertion.i
~$ gcc ... -fno-asynchronous-unwind-tables -S insertion.i
~$ gcc ... -c insertion.s
~$ gcc ... -E inline3.c > inline3.i
~$ gcc ... -fno-asynchronous-unwind-tables -S inline3.i
```

```
main.c:3:13: error: inline function 'InsertionSort'
declared but never defined [-Werror]
    inline void InsertionSort( int *v, int size );
            ^
main.c:3:13: error: inline function 'InsertionSort'
declared but never defined [-Werror]
cc1: all warnings being treated as errors
```

## insertion.s

```
.file "insertion.c"
.ident      "GCC: (Ubuntu 4.8.4-2ubuntu1~14.04.1) 4.8.4"
.section    .note.GNU-stack,"",@progbits
```

The **definition** of an **inline** function must be placed in the **same translation unit** where it will be **inlined**!

How to keep an **inline function definition** in a **separate file**?



# Splitting the Code

## insertion.c (old)

```
inline void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[j + 1] = v[j];
            j = j - 1;
        }
        v[j + 1] = key;
    }
}
```



## insertion.h (new)

```
inline void InsertionSort( int *v, int size ) {
    int j;
    int key;

    for( int i = 1; i < size; i++ ) {
        key = v[ i ];
        j = i - 1;

        while( ( j >= 0 ) && ( v[j] > key ) ) {
            v[j + 1] = v[j];
            j = j - 1;
        }
        v[j + 1] = key;
    }
}
```

## inline3.c (old)

```
inline void InsertionSort( int *v, int size );

int y[5] = { 5, 4, 3, 2, 1 };

int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```



## inline3.c (new)

```
#include "insertion.h"

int y[5] = { 5, 4, 3, 2, 1 };

int main( int argc, char *argv[] ) {
    InsertionSort( y, 5 );
    return y[0];
}
```

Is it possible for a **inline** definition to be **included** in **multiple files**?



# Inline Function in Multiple Files

**insertion.h**

```
inline void InsertionSort( int *v, int size )  
{ ... }
```

**median.c**

```
#include <string.h>  
#include <stdlib.h>  
#include "insertion.h"  
  
float Median( int *v, int size )  
{  
    int *tmp = malloc(sizeof(int) * size);  
    memcpy(tmp, v, sizeof(int) * size);  
  
    InsertionSort(tmp, size);  
  
    float median;  
  
    if (size%2 == 0)  
        median=(tmp[size/2]+tmp[size/2-1])*0.5f;  
    else  
        median = tmp[(int) size/2];  
  
    free(tmp);  
  
    return median;  
}
```

**insertion.h**

**median.c**

**inline4.c**

**inline4.c**

```
#include "insertion.h"  
  
int y[5] = { 5, 4, 3, 2, 1 };  
  
extern float Median(int *v, int size);  
  
int main( int argc, char *argv[] ) {  
    InsertionSort( y, 5 );  
    float m = Median( y, 5 );  
    return ( int ) m + y[0];  
}
```

```
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -E median.c > median.i  
~$ gcc -Wall -Werror -pedantic -O2 -std=c99 -E inline4.c > inline4.i
```



# Inline Function in Multiple Files

InsertionSort()  
inline definition.

median.i

```
...  
inline void InsertionSort(...)  
{  
    ...  
}  
  
float Median(...)  
{  
    ...  
}
```

insertion.h

median.c

median.i

median.s

median.o

inline3.c

inline3.i

inline3.s

inline3.o

inline3

InsertionSort()  
inline definition.

inline4.i

```
...  
inline void InsertionSort(...)  
{ ... }  
  
int y[5] = { 5, 4, 3, 2, 1 };  
  
extern float Median(...);  
  
int main( ... )  
{  
    ...  
}
```

What if we want  
**InsertionSort()**  
to be inline and  
have external  
linkage (e.g.  
someone needs the  
address of  
**InsertionSort()**)?



# Inline Function with External Linkage

- Suppose that `Median()` needs to call `InsertionSort()` through its address.
- Two possible ways are:
  - Redefining `InsertionSort()` as non-inline.  
... which is not cool because implies in duplicate code that will have to be maintained consistent manually.
  - Redeclaring `InsertionSort()` with `extern`.  
... which is nicer, since the duplicated code will be kept consistent automatically!



# Inline Function with External Linkage

## insertion.h

```
inline void InsertionSort( ... )  
{ ... }
```

## median.c (old)

```
#include <string.h>  
#include <stdlib.h>  
#include "insertion.h"  
  
float Median( ... ) {  
    ...  
    InsertionSort(tmp, size);  
    ...  
}
```



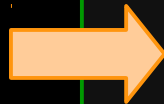
## median.c (new)

```
#include <string.h>  
#include <stdlib.h>  
  
extern void InsertionSort( ... );  
  
float Median( ... ) {  
    ...  
    InsertionSort(tmp, size);  
    ...  
}
```

Forces the inclusion of  
an 'outline' definition of  
InsertionSort().

## inline4.c (old)

```
#include "insertion.h"  
  
int y[5] = { 5, 4, 3, 2, 1 };  
  
extern float Median( ... );  
int main( int argc, char *argv[] ) {  
    ...  
}
```



## inline4.c (new)

```
#include "insertion.h"  
  
int y[5] = { 5, 4, 3, 2, 1 };  
  
extern inline void InsertionSort( ... );  
  
extern float Median(int *v, int size);  
int main( int argc, char *argv[] ) {  
    ...  
}
```



Inspect the intermediary  
code generated!



# Inline Function with External Linkage

## insertion.h

```
inline void InsertionSort( int *v, int size )  
{ ... }
```

## median.c

```
#include <string.h>  
#include <stdlib.h>
```

```
extern void InsertionSort( int *v, int size );
```

```
float Median( int *v, int size )  
{  
    ...  
    InsertionSort(tmp, size);  
    ...  
}
```

## inline4.c

```
#include "insertion.h"
```

```
int y[5] = { 5, 4, 3, 2, 1 };
```

```
extern inline void InsertionSort( int *v, int size );
```

```
extern float Median(int *v, int size);
```

```
int main( int argc, char *argv[] ) {  
    InsertionSort( y, 5 );  
    float m = Median( y, 5 );  
    return y[0];  
}
```

## insertion.h

```
inline InsertionSort(){}  
#include
```

## inline4.c

```
extern inline InsertionSort();  
extern float Median();
```

## inline4.i

```
inline InsertionSort(){};  
extern inline InsertionSort();  
extern float Median();  
InsertionSort();  
Median();
```

## inline4.s

```
InsertionSort: {'outline' func}  
call InsertionSort (inline ??)  
call Median (extern call)
```

## median.c

```
extern void InsertionSort();  
float Median(){};  
InsertionSort();
```

## median.i

```
extern void InsertionSort();  
float Median(){};  
InsertionSort();
```

## median.s

```
Median: {'outline' function}  
call InsertionSort (ext call)
```





# Exercise: inline/const vs. Macros

Compare both codes below:

## nomacro.c

```
int k = 10;

int OffsetFunction( int w ) { return w + k; }

int main( int argc, char *argv[] )
{
    int x;

    if ( argc > 1)
        x = 2;
    else
        x = 1;

    int y = 3 * OffsetFunction( x );

    return y;
}
```

## macro.c

```
#define OFFSET_VALUE 10

#define OFFSET_FUNCTION( val ) ( val + OFFSET_VALUE )

int main( int argc, char *argv[] )
{
    int x;

    if ( argc > 1)
        x = 2;
    else
        x = 1;

    int y = 3 * OFFSET_FUNCTION( x );

    return y;
}
```

Can we **instruct** the **compiler** to generate the (at least approximately) **same low level code** by just **substituting macros** by **const** and **inline**?

