

Sequence Points

“to get a deeper understanding of the language”



Deep C - a 3 day course
Jon Jagger & Olve Maudal

```
#include <stdio.h>

int a[] = { 0,2,4,6,8 };
int b[] = { 0,2,4,6,8 };

int main(void)
{
    int i = a[0] + 1;
    int n = i + a[++i] + b[++i];
    printf("%d\n", n);
}
```

Here is what I get on my machine:

```
$ clang ... main.c
error: multiple unsequenced modifications to 'i' [-Werror,-Wunsequenced]
    int n = v[i++] - v[i++];
               ^      ~~~
```

```
#include <stdio.h>

int a[] = { 0,2,4,6,8 };
int b[] = { 0,2,4,6,8 };

int main(void)
{
    int i = a[0] + 1;
    int n = i + a[++i] + b[++i];
    printf("%d\n", n);
}
```

```
$ gcc ... main.c
$ ./a.out
12
```

```
$ icc ... main.c
$ ./a.out
13
```

```
$ clang ... main.c
$ ./a.out
11
```



```
$ gcc ... main.c
$ ./a.out
12
$ gdb ./a.out
(gdb) set disassembly-flavor intel
(gdb) disassemble main
```

12

gcc

...

```
mov ecx,DWORD PTR [ebp-0xc]
add ecx,0x1
mov DWORD PTR [ebp-0xc],ecx
mov ecx,DWORD PTR [ebp-0xc]
mov ecx,DWORD PTR [eax+ecx*4+0x115]
```

i + a[++i] + b[++i];
4

```
mov edx,DWORD PTR [ebp-0xc]
add ecx,edx
```

i + a[++i] + b[++i];
6

```
mov edx,DWORD PTR [ebp-0xc]
add edx,0x1
mov DWORD PTR [ebp-0xc],edx
mov edx,DWORD PTR [ebp-0xc]
mov edx,DWORD PTR [eax+edx*4+0x135]
```

i + a[++i] + b[++i];
6

```
add ecx,edx
```

i + a[++i] + b[++i];

...

12

```

$ gcc ... main.c
$ ./a.out
13
$ gdb ./a.out
(gdb) set disassembly-flavor intel
(gdb) disassemble main

```

13

icc

...

```

mov  edx,0x1
add  edx,DWORD PTR [ebp-0x18]
mov  DWORD PTR [ebp-0x18],edx

```

$i + a[++i] + b[++i];$
2

```

mov  ecx,0x1
add  ecx,DWORD PTR [ebp-0x18]
mov  DWORD PTR [ebp-0x18],ecx

```

$i + a[++i] + b[++i];$
3

```

shl  edx,0x02
lea  ebx,[eax+0xc2]
add  ebx,edx
mov  edx,DWORD PTR [ebx]

```

$i + a[++i] + b[++i];$
4

```

add  edx,DWORD PTR [ebp-0x18]

```

$i + a[++i] + b[++i];$
7

```

shl  ecx,0x2
lea  ebx,[eax+0xd6]
add  ebx,ecx

```

$i + a[++i] + b[++i];$
6

```

add  edx,DWORD PTR [ebx]

```

$i + a[++i] + b[++i];$

13

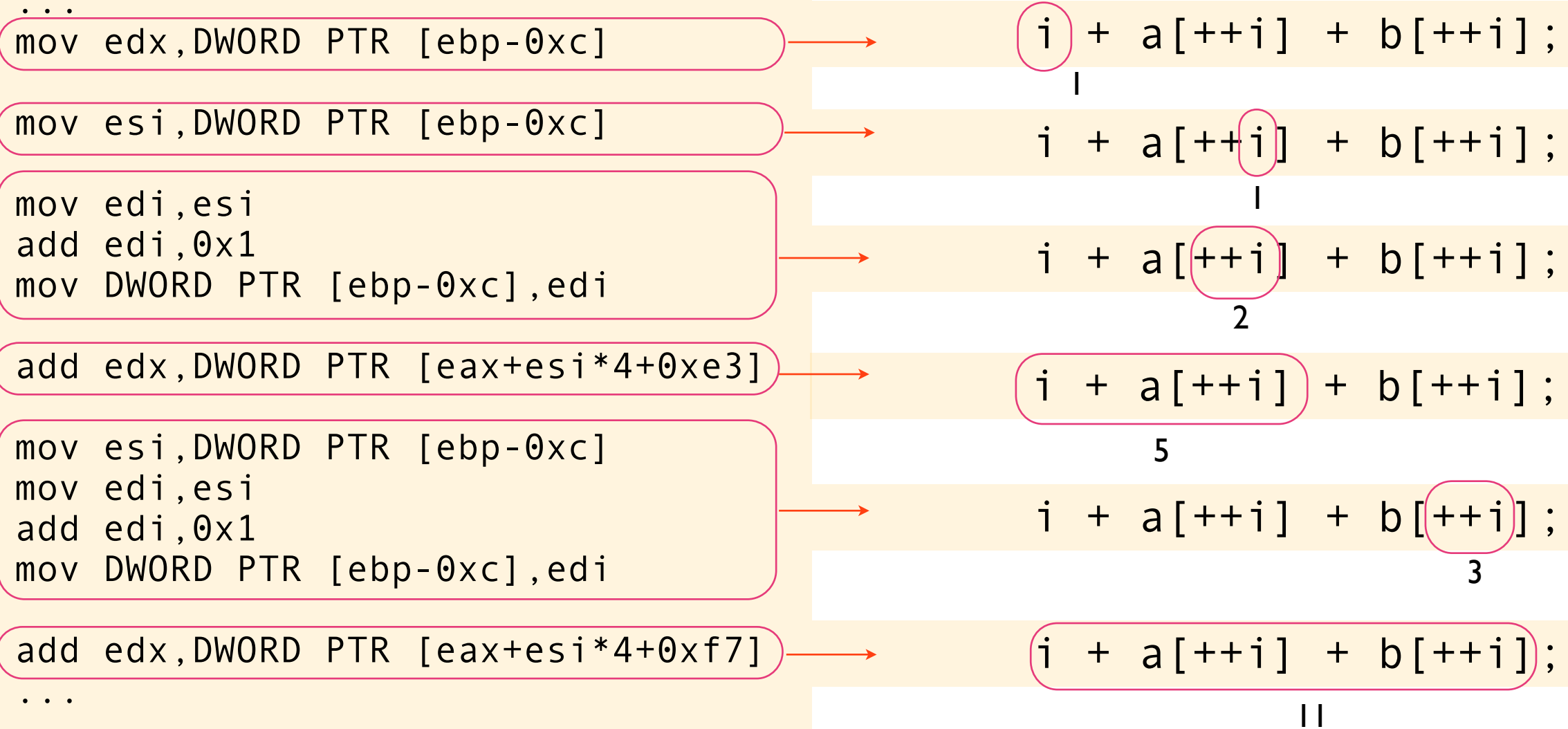
```

$ clang ... main.c
$ ./a.out
11
$ gdb ./a.out
(gdb) set disassembly-flavor intel
(gdb) disassemble main

```

11

clang



5.1.2.3 Program execution. Paragraph 3

Sequenced before is a ... relation between evaluations executed by a single thread, which induces a partial order among those evaluations.

The presence of a *sequence point* between the evaluations of expressions A and B implies that every value computation and side effect associated with A is sequenced before every value computation and side effect associated with B.

If A is not sequenced before or after B, then A and B are *unsequenced*.

In other words:

A sequence point is a point (in time) in the program's execution sequence when all previous side effects will have already taken place and when all subsequent side-effects will not yet have taken place.

Only sequence points govern this sequencing!

6.5 Expressions. Paragraph 2

If a side effect on a scalar object is unsequenced relative to either a different side effect on the same scalar object or a value computation using the value of the same scalar object, the behaviour is *undefined*.

6.5 Expressions. Paragraph 3

Except as specified later, side effects and value computations of subexpressions are *unsequenced*.

In other words, by default, subexpressions are *unsequenced*.



Sequence Points occur...

- After evaluation of the function designator and the actual arguments but before the actual function call (6.5.2.2 paragraph 10)

- After evaluation of first operand of these operators.

&& logical-and (6.5.13 paragraph 4)

|| logical-or (6.5.14 paragraph 4)

?: ternary (6.5.14 paragraph 4)

, comma (6.5.17 paragraph 2)

- At the end of a full declarator.

6.7.5. Declarators. paragraph 3.

A full declarator is a declarator that is not part of another declarator.

- At the end of a full expression.

6.8 Expressions. paragraph 4.

A full expression is an expression that is not a sub-expression of another expression or declarator.

Full Declarator?

6.7.5. Declarators. paragraph 3.

A full declarator is a declarator that is not part of another declarator.

This comma is a punctuator and *not* a comma operator

`int x = a++, y = a++;`

`int`

declarator

`x = a++`

`,`

declarator

`y = a++`

this `a++` is *sequenced before* this `a++`

Full Expression?

6.8 Expressions. paragraph 4.

A full expression is an expression that is not a sub-expression of another expression or declarator.

```
return n % 2 == 0;
```

n is an expression
n is not a full expression

```
return n % 2 == 0;
```

n % 2 is an expression
n % 2 is not a full expression

```
return n % 2 == 0;
```

n % 2 == 0 is an expression
n % 2 == 0 is a full expression

```
return n % 2 == 0;
```

return n % 2 == 0;
is a statement



```
n = n++
```

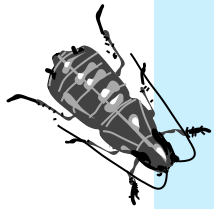
undefined?



```
n + n++
```

undefined?

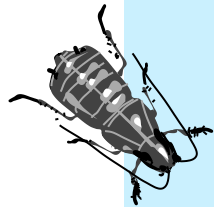




`n = n++`

undefined

[n =]
(side effect on n)
is *unsequenced* relative to
[n++]
(different side effect on n)



`n + n++`

undefined

[n++]
(side effect on n)
is *unsequenced* relative to
[n]
(value computation using the value of n)

```
f(n, n++);
```

undefined?





```
f (n , n++) ;
```

undefined*

[n++]

(side effect on n)

is *unsequenced* relative to

[n]

(value computation using the value of n)

* the comma in f(n,n++) is a punctuator, not an operator

```
if (n++ & n)
{
    ...
}
```

undefined?

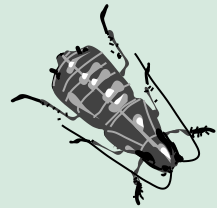


```
if (n++ && n)
{
    ...
}
```

undefined?




```
if (n & n++)  
{  
    ...  
}
```



undefined

n++ is
unsequenced
relative to n

```
if (n++ && n)  
{  
    ...  
}
```

not undefined*

n++ is
sequenced before
n

* but still very poor style

in this code fragment it is "intuitively obvious"
that n incremented before being used
as an argument to `func()`



```
if (n++ < 10) {  
    func(n);  
}
```

How do you *know* this?



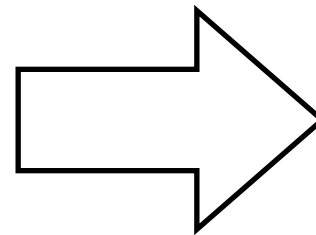
For sure?



because `n++ < 10` is the *full-expression*
controlling the if statement

and there is a sequence-point at the
end of each *full-expression*

if (*expression*)
statement



if (*full-expression*)
statement

```
if (n++ < 10)
{
    func(n);
}
```

`n++` is
sequenced before
`n`

```
int x = n, n++;
```

undefined?



```
int x = (n, n++);
```

undefined?



```
int x = n, n++;
```

doesn't compile!

```
int x = (n, n++);
```

not undefined

*n is
sequenced before
n++*

```
int f(int * p, int * q)
{
    return (*p) - (*q)++;
}
```

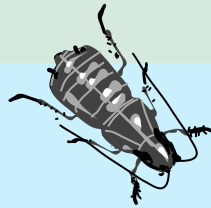
undefined?



```
int f(int * p, int * q)
{
    return (*p) - (*q)++;
}
```

```
int eg(int n)
{
    return f(&n, &n);
}
```

undefined



n is *unsequenced*
relative to n++

```
int eg(int n, int m)
{
    return f(&n, &m);
}
```

not undefined!

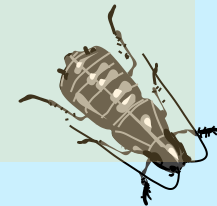
p and q point to
different variables

```
void swap_trick(int a, int b)
{
    a ^= b ^= a ^= b;
}
```

undefined?




```
void swap_trick(int a, int b)
{
    a ^= b ^= a ^= b;
}
```



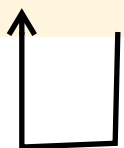
undefined

side effect on a is *unsequenced* relative to different side effect on a
side effect on b is *unsequenced* relative to different side effect on b

Precedence?

- precedence occurs at compile time
- it governs what operator an operand binds to
- you determine *what* happens

```
int n = a() * b() + c();
```

A diagram consisting of a vertical line with an upward-pointing arrow at the bottom, and a horizontal line extending to the right from the top of the vertical line, ending under the asterisk operator in the code above.

- order of evaluation occurs at run time
- it is governed *only* by sequence points
- compiler determines *how* it happens



```
int _reg1 = c();  
int _reg2 = a();  
int _reg3 = b();  
...
```

Summary

- only sequence points govern order of evaluation
- 1. before function call
- 2. end of full declarator
- 3. operators && || ?: ,
- 4. end of full expression
- precedence is different