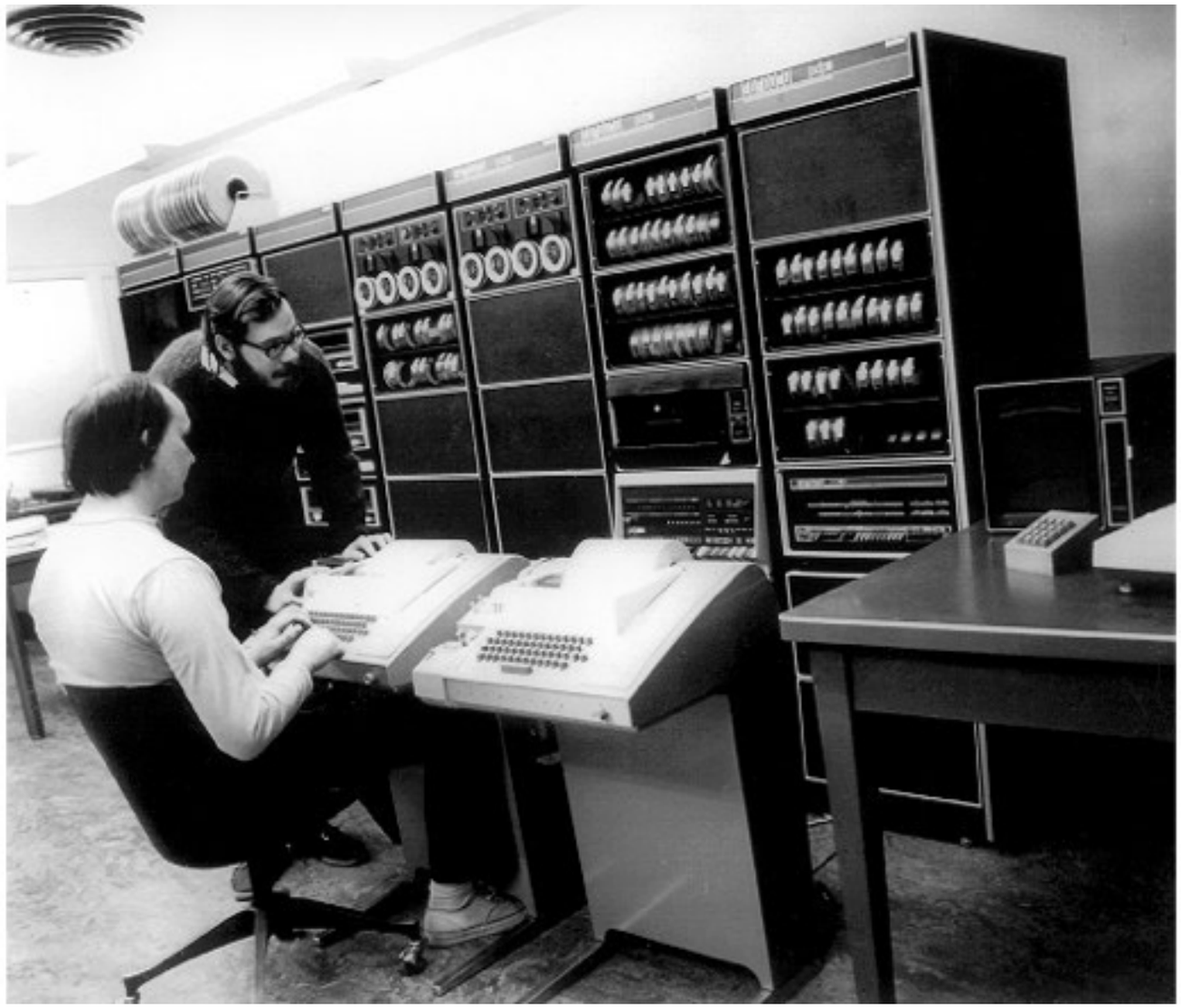
Sequence Points

"to get a deeper understanding of the language"



Deep C - a 3 day course

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main.c

```
#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++];
             ^       ~~
```

main.c

```c
#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

```
$ icc ... 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 ebc,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

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

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

```
mov esi,DWORD PTR [ebp-0xc]
```

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

```
mov edi,esi
add edi,0x1
mov DWORD PTR [ebp-0xc],edi
```

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

2

```
add edx,DWORD PTR [eax+esi*4+0xe3]
```

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

5

```
mov esi,DWORD PTR [ebp-0xc]
mov edi,esi
add edi,0x1
mov DWORD PTR [ebp-0xc],edi
```

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

6

```
add edx,DWORD PTR [eax+esi*4+0xf7]
```

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

11

```
...
```

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 paragraph10)

- 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.

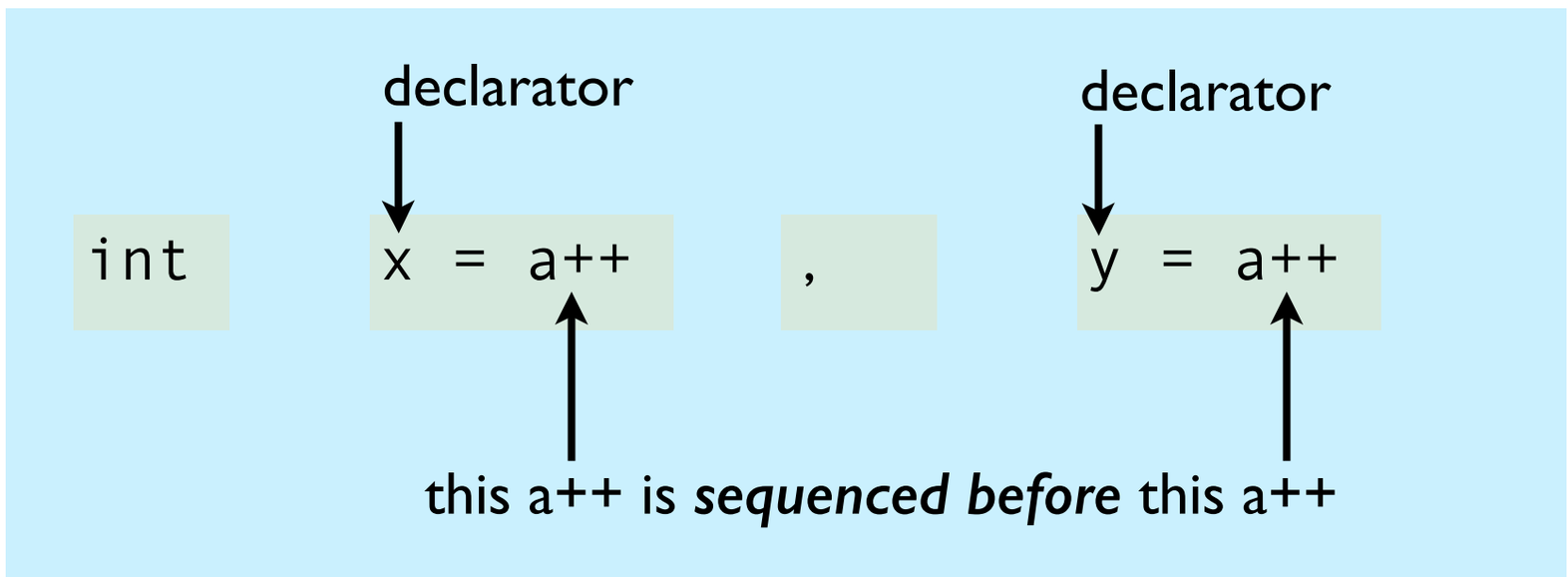
- At the end of a full expression.
  6.8 Expressions. paragraph 4.
  A full expression is an expression that is not a sub-expression of another expression or declarator.

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++;
```



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);
}
```

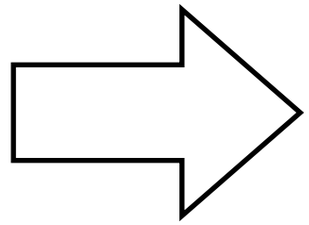
How do you ***know*** this?

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

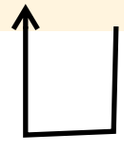
side effect on a is ***unsequenced*** relative to different side effect on a

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();
```



- 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();
reg2 * reg3 + reg1
```

```
int reg1 = a();
int reg2 = b();
int reg3 = c();
reg1 * reg2 + reg3
```

Summary

- precedence is not the same as order of evaluation
- only sequence points govern order of evaluation
  - before function call
  - end of full declarator
  - operators && || ?: ,
  - end of full expression