

Introduction to Programming

Part I

Lecture 3

The C Language: Statements & Expressions

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What We Have Considered Before:

- The memory model: code, heap & stack.
- The typical C program structure.
- How C programs are compiled and built.
- C programs and the notion of stack.
- Variable scopes and program blocks.
- The notion of **type**. Static and dynamic typing. Type categories. The C type system.
- Storage class specifiers: **auto**, **static**, **extern**
- **Pointers & arrays**

Some Key Points From the Previous Lecture

Storage Class Specifiers

auto
static
extern

Are introduced together with type specifiers in object declarations

```
int a;  
static char b;  
extern float c;  
  
void f()  
{  
    double d;  
    static int e;  
    auto int f;  
}
```

19/27

a is the **global non-static object**

- it "belongs" to the whole program;
- it is available throughout the program;
- it is created only once: before the program starts.

b is the **global static object**

- it "belongs" to the whole program;
- it is available **only from within the translation unit** it belongs to;
- it is created only once: before the program starts.

c is the **global external object**

- this is not a definition but declaration; it's assumed that the object is (really) defined in some other translation unit;
- The memory for the object is not allocated here but in other TU.

d and **f** are **automatic local objects**

- it "belongs" to the function in which it's declared;
- it's available only from within the function (i.e., it's local to the function);
- it's created each time the function is invoked.

e is the **local static object**

- it "belongs" to the function in which it's created;
- it is available only from within the function;
- it is created only once: before the program starts.

Some Key Points From the Previous Lecture

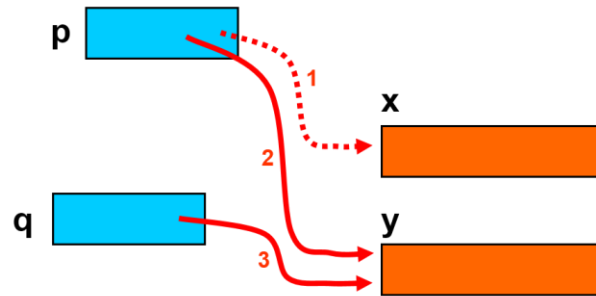
Pointers

1. Pointer:

An object containing an address to some other object

```
int x;  
int* p;  
...  
p = &x; 1
```

Unary "address-of"
operator



```
int y;  
...  
p = &y; 2
```

```
int* q;  
...  
q = p; 3
```

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Some Key Points From the Previous Lecture

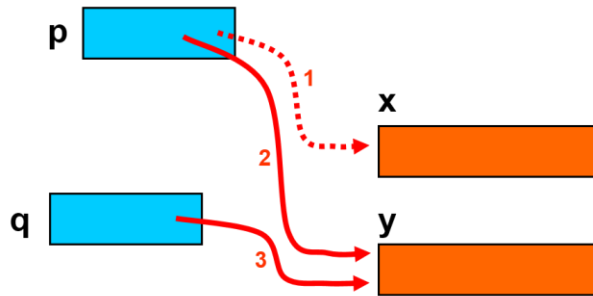
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q = p; 3
```

Pointers

3. Operators on pointers

&object

Taking address of object

Unary prefix operator

```
int x;  
int* p;  
...  
p = &x;
```

***pointer**

Dereferencing:
Getting object pointed
to by "pointer"

Unary prefix operator

```
int x;  
int* p = &x;  
...  
*p = 777; // x is 777  
int z = *p+1; // z is 778
```

Some Key Points From the Previous Lecture

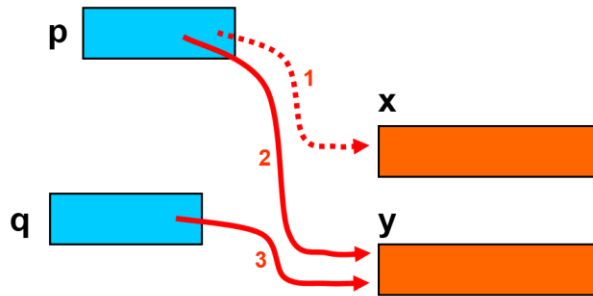
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```
int* q;  
...  
q = p; 3
```

```
pointer+i  
pointer-i  
pointer++  
pointer--  
ptr1-ptr2
```

Operators
defined on
pointers

Pointers

3. Operators on pointers

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Taking address of object

Unary prefix operator

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Outline: Today

- Dynamic memory management
- Statements
- Expressions

Global, Local & Dynamic Objects

Global & static objects Global storage

Are created on program's start and exist ("live") until program is completed.

Live in the **global scope**.

Are accessible ("visible") within the translation unit they are declared in, OR within the whole program.

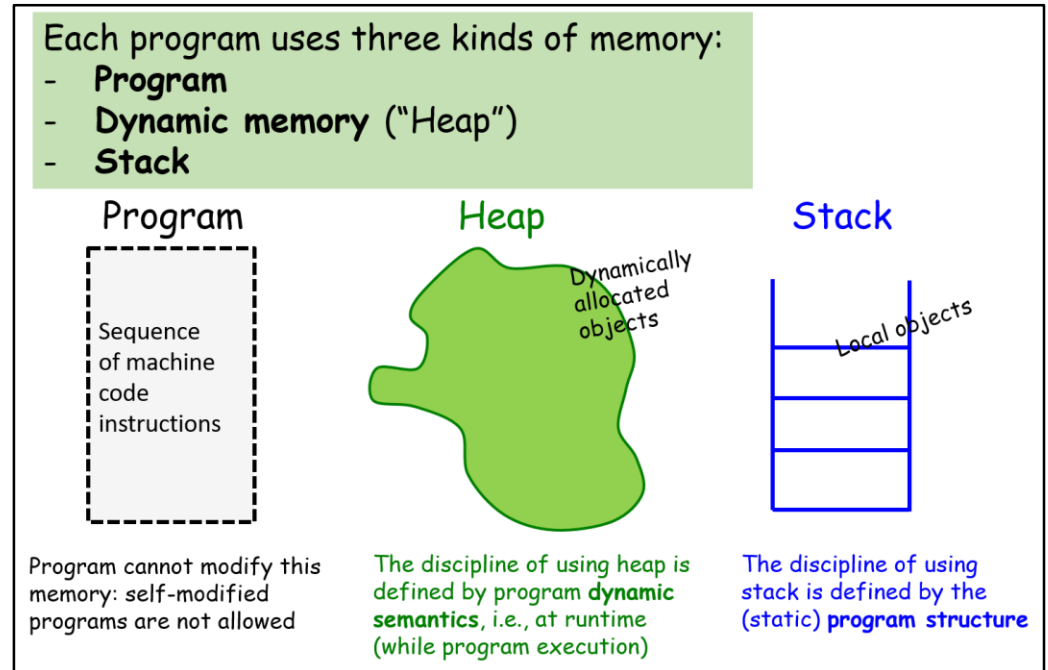
Local objects Stack

Are created when a function is invoked or when the control flow enters a block, and disappear on return or on exit from the block.

Dynamic objects Heap

Are created and destroyed on arbitrary moments while program execution, following the program logic.

Do you remember the slide from the 1st lecture?



Global, Local & Dynamic Objects

How global & local objects are created?

- **By their declarations**

How dynamic objects are created?

- **Using special standard functions from the C library**

Global, Local & Dynamic Objects

How global & local objects are created?

- By their declarations


How dynamic objects are created?

- Using special standard functions from the C library

Globals & locals:
an example

```
int x;  
int* ptr;  
void f(int p)  
{  
    int* local = &x;  
    if ( p > 0 )  
    {  
        float m = 0.5 ;  
        ...  
    }  
    ...  
}
```

`m` is unknown outside
of the loop



`x` & `ptr` are **global objects**; they are created on the program's start and exist until its end

`p` & `local` are **local objects**; they are created when `f` function is invoked and disappear on return from `f`

`m` is the **local object**; it is created when the control flow enters the then-branch of `if` and disappears on return from this block

Dynamic Objects

How dynamic objects are created (and destroyed)?

- Using special standard functions from the C library

```
void* malloc ( int size )  
{  
    ...  
    Allocation algorithm  
    ...  
}
```

```
void free ( void* ptr )  
{  
    ...  
    Deallocation algorithm  
    ...  
}
```

Dynamic Objects

How dynamic objects are created (and destroyed)?

- Using special standard functions from the C library

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void* malloc ( int size )  
{  
    ...  
    Allocation algorithm  
    ...  
}
```

```
void free ( void* ptr )  
{  
    ...  
    Deallocation algorithm  
    ...  
}
```

- Specification is a bit simplified.
- The function allocates space for an object whose size (in bytes) is passed via the parameter.
- The function returns a pointer to the memory allocated.
- The pointer is "untyped" (`void*`).
- There are more allocation functions in the library.

Library Organization

Each translation unit is usually represented by **two source files**:

- with forward declarations ("interface");
- with full declarations ("implementation").

To remind...

Library Organization

Each translation unit is usually represented by two source files:

- with forward declarations ("interface");
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To remind...

Do you remember the slide from the 1st lecture?

```
void* malloc(int size);  
void free(void* ptr);
```

...
And many other function headers ("prototypes")

Provided as text

stdlib.h

stdlib.c

```
void* malloc(int size)  
{
```

...
Implementation

...
}

...
And implementations of many other standard functions

...

Precompiled

```
int Max(int a, int b)  
{  
    if ( a > b )  
        return a;  
    else  
        return b;  
}
```

Max.c

```
void input(int* x, int *y);  
int Max(int a, int b);
```

```
int main()  
{  
    int x, y;  
    input(&x,&y);  
    return Max(x,y);  
}
```

Main.c

```
void input(int* x, int *y)  
{  
    ...  
}
```

Input.c

- Typically, any C program consists of several **translation units** each of which is located in a separate source file.
- The **independent compilation principle**; each TU gets compiled **independently** from others.

Linking

Object
file 1

Object
file 2

Object
file 3

The
resulting
program
ready for
execution

Dynamic Objects

How dynamic objects are created?

- Using special standard functions from the C library

Example

```
struct S { int a, b; };
```

This is struct type declaration

Dynamic Objects

How dynamic objects are created?

- Using special standard functions from the C library

Example

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

In order to use `malloc`,
we should add its header

```
struct S { int a, b; };
```

This is struct type declaration

```
void* ptr = malloc(sizeof(struct S));
```

Here, we dynamically allocate
memory suitable to keep objects
of type `struct S`...

Dynamic Objects

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#include <stdlib.h>
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struct S { int a, b; };
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```
void* ptr = malloc(sizeof(struct S));
```

```
struct S* s = (struct S*)ptr;
```

...and **convert** the void pointer type
to the type of pointer to `struct S`.

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Dynamic Objects

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of type `struct S`...

```
s->a = 5;
```

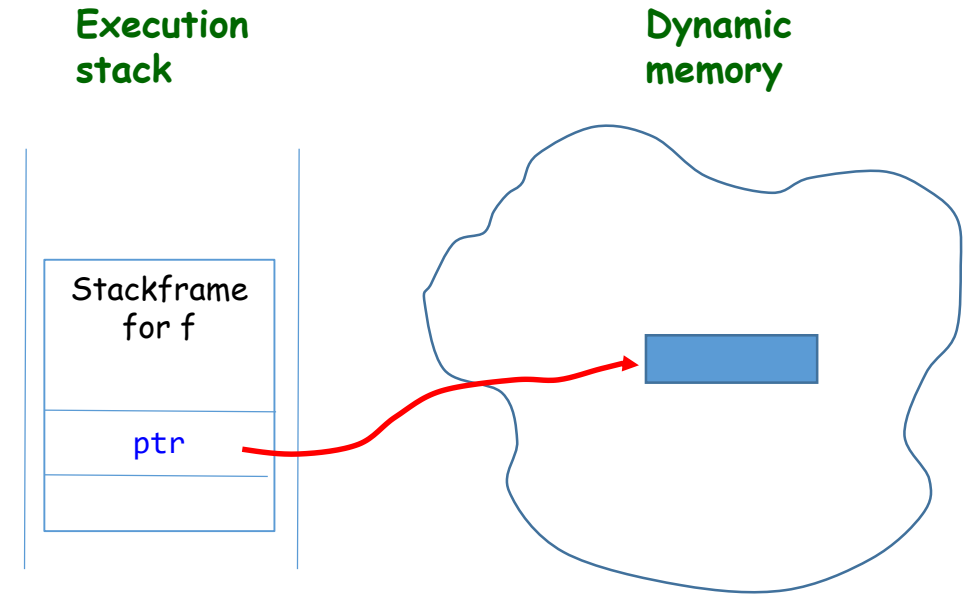
```
...
```

After that, we can use `s` to get
access to elements of `struct S`.

Dynamic vs Static Objects

```
...  
void f()  
{  
    long* ptr = (long*)malloc(long);  
    ...  
}  
...  
f();
```

What happens when the control flow leaves the function body?



Dynamic vs Static Objects

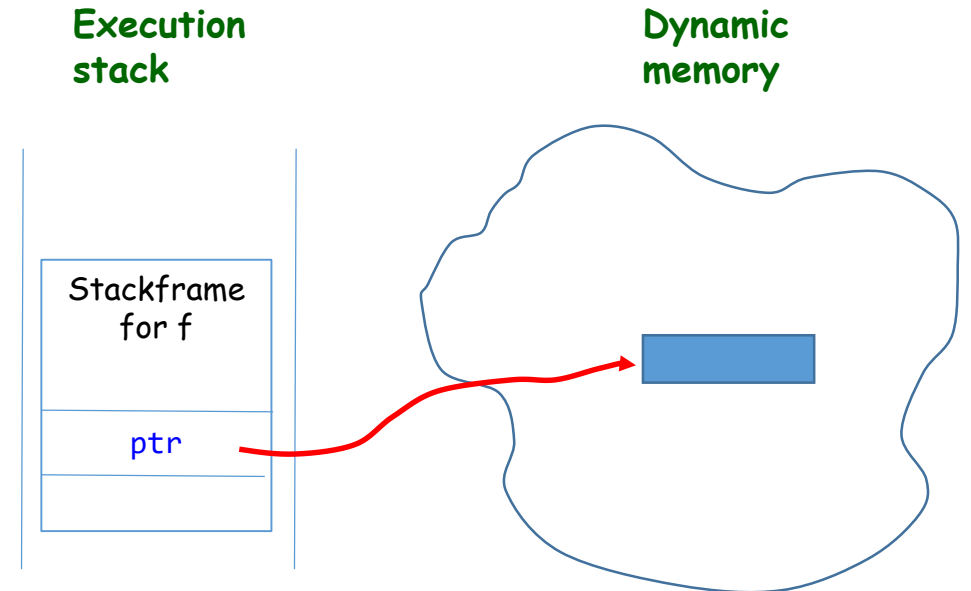
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...  
void f()  
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    long* ptr = (long*)malloc(long);  
    ...  
}  
...  
f();
```

Memory allocated by `malloc` exists until it is explicitly released by `free`

What happens when the control flow leaves the function body?

- `ptr` variable is local therefore it is disappeared in accordance with the scoping rules...
- ...but the object pointed to by `ptr` still exists!..
- ...but there is no way to get access to it!

Memory leak!



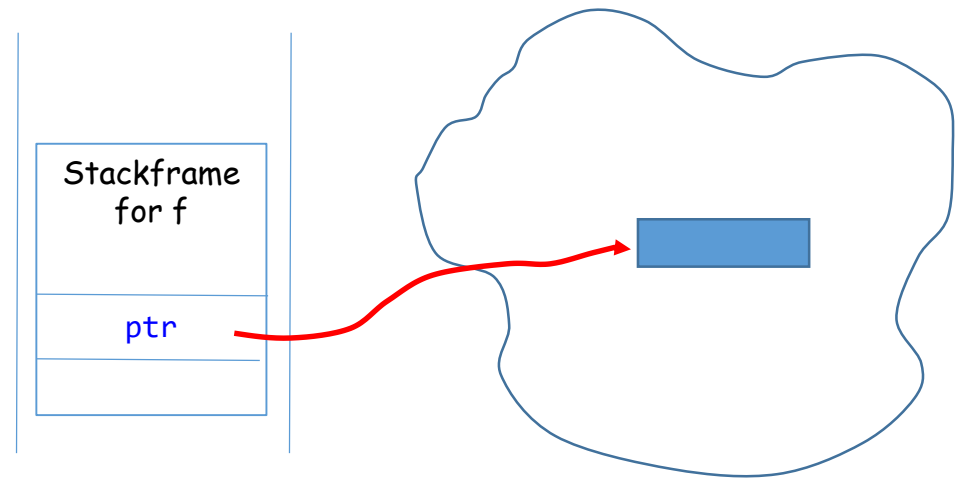
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Execution
stack

Dynamic
memory



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Memory leak!

```
void f()  
{  
    long* ptr = (long*)malloc(long);  
    ...  
    free(ptr);  
}
```

Statements in C

The “standard” set of statements

- Selection statements: if & switch
- Iteration statements: for-, while- & do-loops
- Jump statements: goto, return, break & continue
- Compound statements, or blocks
- Empty, or null statements

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What's missing? 😊

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Compound statement is a **sequence of statements and/or declarations**; therefore, a declaration within a block is considered **as a statement**.

What's missing? 😊

- ~~Assignments~~
- ~~Function calls~~

In addition to the “standard” set there are two non-conventional kinds of statements:

- Declaration statement
- Expression statement

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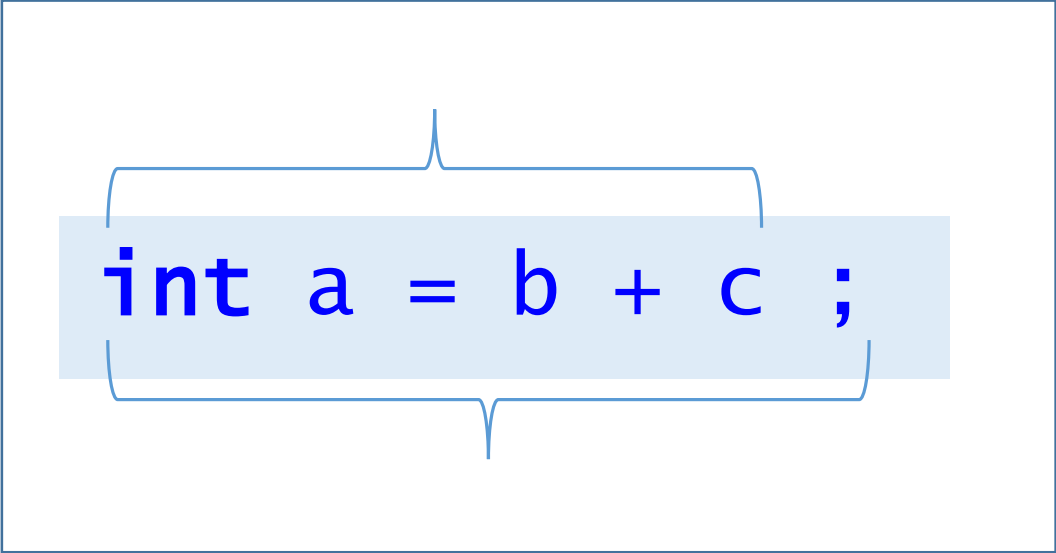
The common rule:
Statements do not issue values
(do not produce results)

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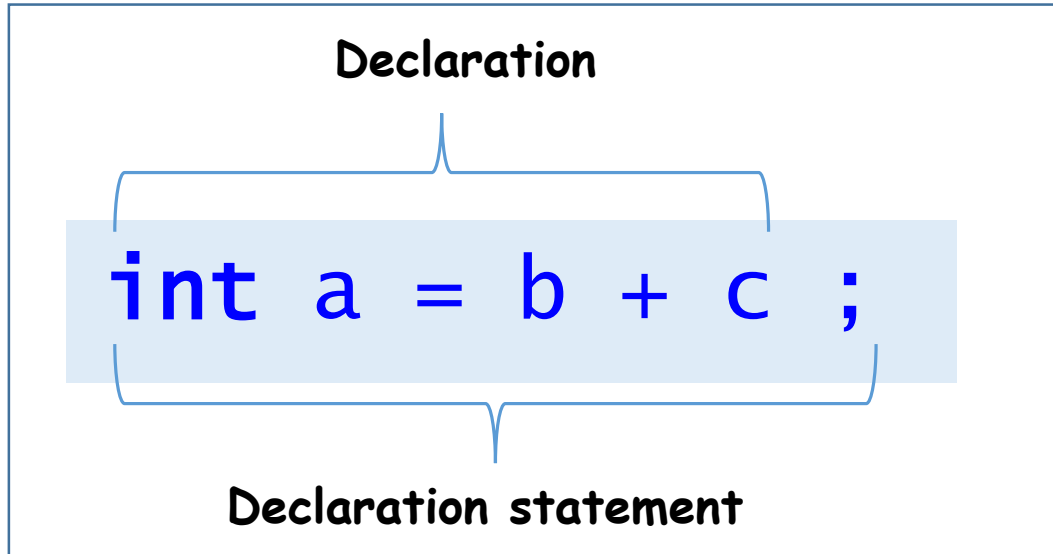
Statements in C



The diagram shows the C statement `int a = b + c ;` enclosed in a light blue rectangular box. Above the box, a horizontal curly brace spans the width of the box, with a vertical line extending upwards from its center. Below the box, another horizontal curly brace spans the width of the box, with a vertical line extending downwards from its center. The text `int a = b + c ;` is displayed in blue font within the box.

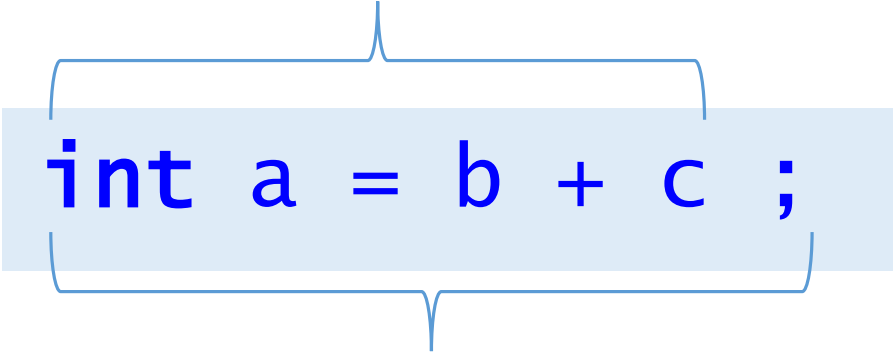
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```

Statements in C



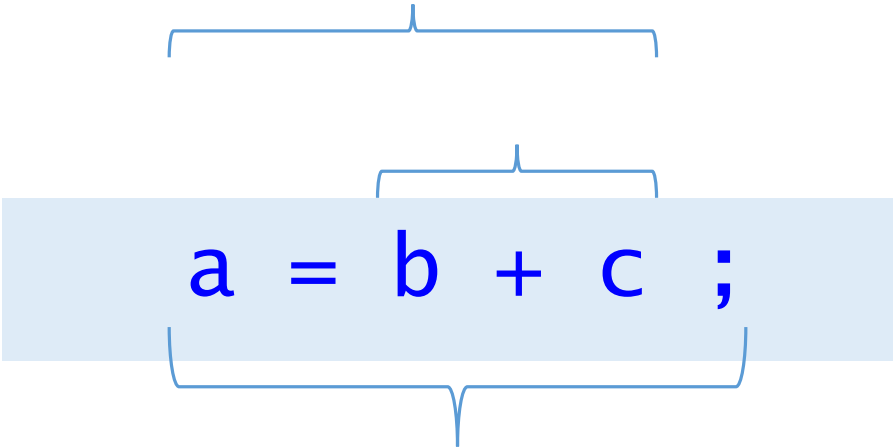
Statements in C

Declaration



```
int a = b + c ;
```

Declaration statement



```
a = b + c ;
```

Statements in C

Declaration

```
int a = b + c ;
```

Declaration statement

Expression

Expression

```
a = b + c ;
```

Expression statement

`b+c` is the expression; its result is the **sum** of values of `b` and `c` variables;

`a=b+c` is the **expression as well**; its result is the value of its right part;

`a=b+c;` is the **statement**; it **doesn't** produce a result (or, the result of the expression is **discarded**).

Statements in C

Declaration

```
int a = b + c ;
```

Declaration statement

The common rule:
Statements do not issue values
(do not produce results)

The conclusion: declaration statements and
"usual" statements can go in any order.

Expression

Expression

```
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Expression Statements

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Expression Statements

Semantics

- b and c are expressions. The results of their execution is the current values of corresponding variables.

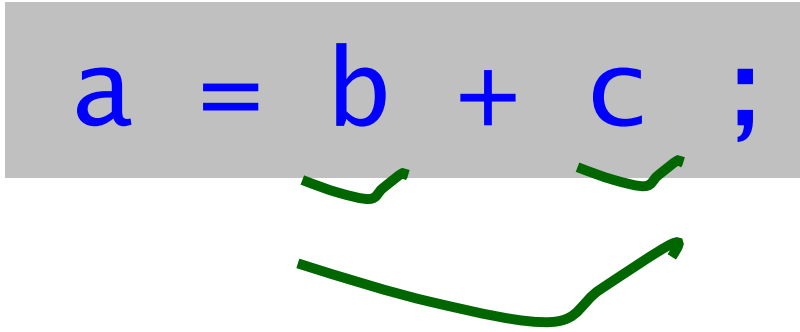
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Expression Statements

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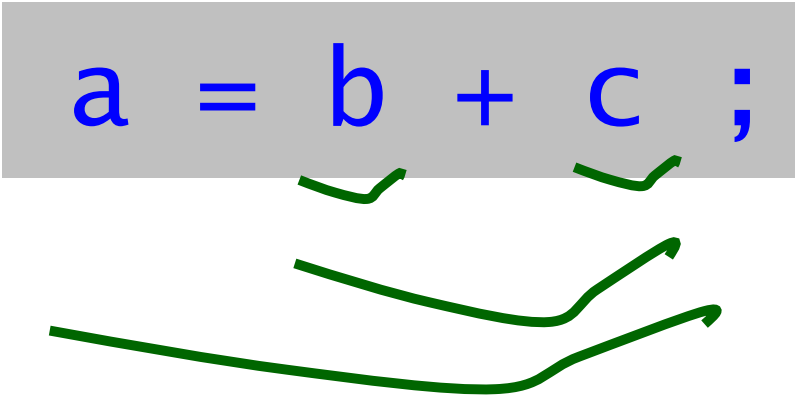


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Expression Statements

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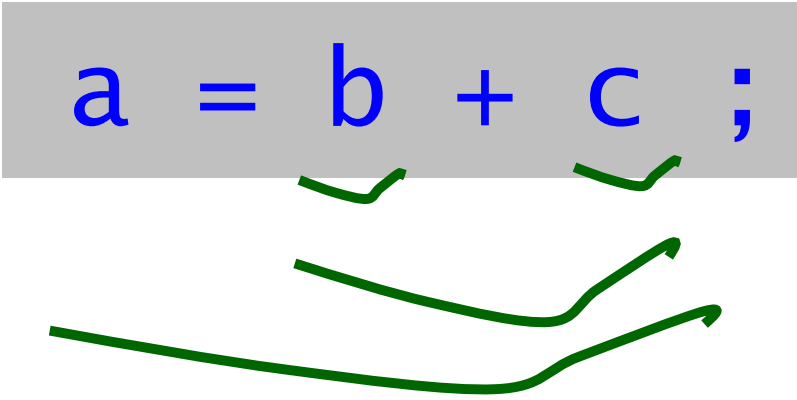
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Expression Statements

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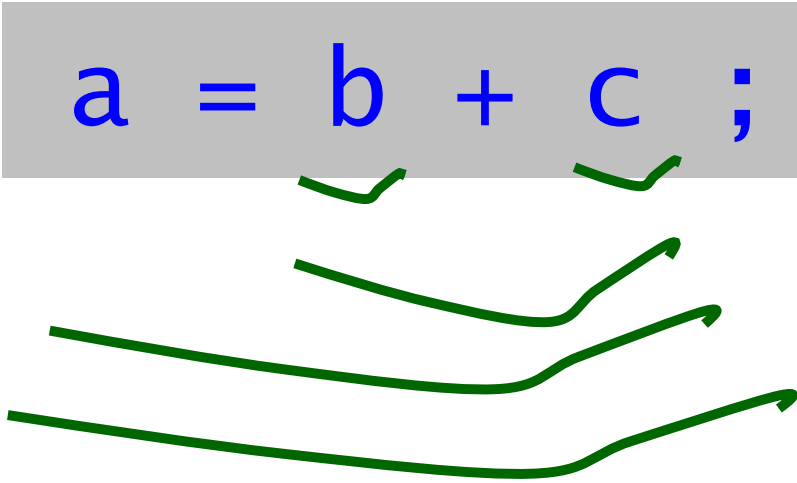
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- $a=b+c$ is the expression called **assignment**. It's semantics is as follows: the value of the right-part expression gets assigned by the reference to memory denoted by the left- part expression. **The result of the assignment is the value of its right-part expression.**



Expression Statements

Semantics

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Expression Statements

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- $a=b+c;$ is the **expression statement**. Its semantics is: the containing expression (assignment) is executed, and its result (if any) is **discarded**.

$a = b + c ;$



Therefore, the assignment is used only for its side effect.

$f(x) ;$

Function call. The same idea: even if f returns a value, it is discarded.

What is "expression statement":

expression ;

Statements in C: Conditionals

Official name:
selection statements

selection-statement:

if (*expression*) *statement*

if (*expression*) *statement* **else** *statement*

switch (*expression*) *statement*

Statements in C: Conditionals

Official name:
selection statements

selection-statement:

if (expression) statement

if (expression) statement **else** statement

switch (expression) statement

Controlling expression

Statements in C: switch

selection-statement:

...

switch (*expression*) *statement*

Statements in C: switch

selection-statement:

...

switch (*expression*) *statement*

The type of the controlling
expression should be integer

Any statement is allowed here!

Statements in C: switch

selection-statement:

...

switch (*expression*) *statement*



The diagram shows two arrows originating from explanatory text blocks below the switch statement. One arrow points from the text 'The type of the controlling expression should be integer' to the 'expression' part of the switch statement. The other arrow points from the text 'Any statement is allowed here!' to the 'statement' part of the switch statement.

The type of the controlling expression should be integer

Any statement is allowed here!

Labeled-statement:

identifier : *statement*

case *constant-expression* : *statement*

default : *statement*

Statements in C: switch

selection-statement:

...
switch (*expression*) *statement*

The type of the controlling
expression should be integer

Any statement is allowed here!

Labeled-statement:

identifier : *statement*
case *constant-expression* : *statement*
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```
int x, y;  
...  
switch ( x+1 )  
{  
    case 1: y++;  
    case 2: y += 7; break;  
    default:  
        printf("%s\n", "illegal value of x");  
}
```

Statements in C: switch

selection-statement:

...
switch (*expression*) *statement*

The type of the controlling expression should be integer

Any statement is allowed here!

Labeled-statement:

identifier : *statement*
case *constant-expression* : *statement*
default : *statement*

The "body" of switch is the compound statement

```
int x, y;  
...  
switch ( x+1 )  
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    case 1: y++;  
    case 2: y += 7; break;  
    default:  
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}
```

After the increment, the control flow goes to the next statement!

Completes the switch-statement

Statements in C: Loops

Official name:
iteration statements

iteration-statement:

```
while ( expression ) statement  
do statement while ( expression ) ;
```

```
for ( expressionopt ; expressionopt ; expressionopt ) statement  
for ( declaration expressionopt ; expressionopt ) statement
```

Semantics

An iteration statement causes a *statement* called the *loop body* to be executed repeatedly until the controlling *expression* compares equal to 0.

Statements in C: Loops

iteration-statement:

```
while ( expression ) statement  
do statement while ( expression ) ;  
...
```

Statements in C: Loops

The evaluation of the controlling expression takes place **before** each execution of the loop body.

0, 1, 2, or more iterations

iteration-statement:

```
while ( expression ) statement  
do statement while ( expression ) ;  
...
```

The evaluation of the controlling expression takes place **after** each execution of the loop body.

1, 2, or more iterations

Statements in C: Loops

iteration-statement:

...

for (*expression_{opt}* ; *expression_{opt}* ; *expression_{opt}*) *statement*

for (*declaration* *expression_{opt}* ; *expression_{opt}*) *statement*

Statements in C: Loops

Is evaluated **first**,
and **only once**

Controlling expression: it is
evaluated **before each**
execution of the body

Is evaluated **after each**
execution of the body;
its value is discarded

iteration-statement:

...

```
for ( expressionopt ; expressionopt ; expressionopt ) statement  
for ( declaration expressionopt ; expressionopt ) statement
```

The scope of the
declaration is the
whole iteration-
statement

Statements in C: Loops

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and **only once**

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iteration-statement:

...

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for ( expressionopt ; expressionopt ; expressionopt ) statement  
for ( declaration expressionopt ; expressionopt ) statement
```

The scope of the
declaration is the
whole iteration-
statement

Typical example

The scope of **i** is
the whole loop

Evaluates before
each iteration

```
for ( int i=0; i<10; i++ )  
{  
    A[i] = A[i]*A[i];  
}  
...
```

i is unknown
outside of
the loop

The value of the
expression (if any) is
discarded

Statements in C: Jumps

Official name:
jump statements

```
jump-statement:  
    goto identifier ;  
    continue ;  
    break ;  
    return expressionopt ;
```

Statements in C: Jumps

Official name:
jump statements

jump-statement:

```
goto identifier ;  
continue ;  
break ;  
return expressionopt ;
```

```
void f()  
{
```

```
    NextIteration:
```

```
    Some code
```

```
    if ( condition )
```

```
        goto NextIteration;
```

```
    else
```

```
        return;
```

```
}
```

Unconditional jump to
a labeled statement

Return the control
to the caller

Statements in C: Jumps

Official name:
jump statements

jump-statement:

```
goto identifier ;  
continue ;  
break ;  
return expressionopt ;
```

```
void f()  
{
```

```
    NextIteration:
```

```
    Some code
```

```
    if ( condition )
```

```
        goto NextIteration;
```

```
    else
```

```
        return;
```

```
}
```

Unconditional jump to
a labeled statement

Return the control
to the caller

The infinite loop

```
for ( ; ; )
```

```
{
```

```
    ...
```

```
    if ( condition2 ) continue;
```

```
    if ( condition1 ) break;
```

```
    ...
```

```
}
```

```
...
```

The jump to the next
iteration

The jump outside the
compound statement

Statements in C

```
int f()
{
    int i = 3;
    for ( int j=0; j<20; j++ )
    {
        int k = 0;
        if ( j<=10 )
        {
            int i = 7;
            k += g(i);
        }
        else
        {
            h(k+i);
            int j = g(k+i);
            k += j*i;
        }
    }
    return i*i;
}
```

- Function body is a block (compound statement). It contains a sequence of statements. Both "ordinary" and declaration statements are in the block.
- The body of the for-loop is (also) a block with one declaration statement and one "ordinary" statement.

Statements in C

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int f()
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    for ( int j=0; j<20; j++ )
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```

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- (*) This is the expression statement. It contains the expression. The value of the expression is **discarded** (only **side effect** of the expression statement matters).

Statements in C

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    for ( int j=0; j<20; j++ )
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        if ( j<=10 )
        {
            int i = 7;
            k += g(i); *
        }
        else
        {
            h(k+i); **
            int j = g(k+i);
            k += j*i;
        }
    }
    return i*i;
}
```

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- (**) This is also the expression statement. It contains the function call. If the `h` function returns the value, it's **discarded**.

Statements in C

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            h(k+i); **
            int j = g(k+i); ***
            k += j*i;
        }
    }
    return i*i;
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```

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- (**) This is also the expression statement. It contains the function call. If the `h` function returns the value, it's **discarded**.
- (***) This is declaration statement. Here, the position of the declaration is not at the beginning of the block - being a statement, it can occur at any position within the block.

Expressions in C

“Expression” is a formula for calculating values.

- Any expression (almost any 😊) issues a value.

In general, expressions are built of

- Operands
- Operators
- Parentheses

using ordinary rules (as in many other programming languages).

```
f() * (a+b) - *p++;
```

Expressions in C

Primary expression elements:

- Identifier (designates a variable/constant/function)

fun abs ptr_fun

Identifiers designate corresponding entities:
Either values of variables/constants or function addresses

- Literal: integer/floating/string

123 0xFE 0.01E-2 "string"

Literals designate themselves

- Subexpression enclosed in parentheses

(a-b)

Subexpressions designate values of enclosed expressions.

Expressions in C

Secondary expression elements ("postfix expressions")

- are built on top of primary expressions:

- Array subscripting

```
arr[i+j*2]
```

Value of or reference to an array element.

- Function call

```
fun(*p,&x,777+y)
```

The result of the function call.

- Structure/union member access

```
ptr->m     s.m
```

Value of or reference to a struct member.

- Postfix decrement/increment

```
ptr--     arr++
```

The result is the initial pointer (YES!)
The side effect: the pointer gets moved to the previous/next element depending of the type pointer to by the pointer

Expressions in C

Next (higher-level) building blocks: unary expressions

- are built on top of postfix expressions:

- Prefix increment/decrement

`--p ++x`

Result: the value of the operand increased or decreased by one.

- Address & indirection

`&x *(p+1)`

Result: the address of the operand OR the value pointed to by the pointer from the operand.

- Unary plus/minus

`+X -V`

The value from the operand (not changed) OR the original value with the inverted sign.

- Bitwise complement & logical negation

`~V !V`

The result: the initial value inverted or negated

- Sizeof operator

`sizeof (T) sizeof a+b`

The result: an integer value

Expressions in C

The highest-level building blocks for expressions:
binary expressions:

- Additive & multiplicative operators

`a+b` `b-c` `c*d` `d/e` `e%f`

- Relational & equality operators

`a<b` `a<=b` `a>b` `a>=b` `a==b` `a!=b`

- Bitwise shift operators

`a << b` `a >> b`

- Bitwise logical operators

`a & b` `a | b` `a ^ b`

- Logical operators

`a && b` `a || b`

Expressions in C

These are also binary operators:

- Assignment operators

`a = b`

`a+=b a-=b a*=b a/=b a%=b`
`<<= >>=`
`&= ^= |=`

- Comma operator (!!)

`expr1 , expr2`

The left expression is evaluated; its value is **discarded**. Then the second expression is evaluated. Its value is the result of the whole comma expression.

-
- Conditional operator

`expression ? expression : expression`

The single **ternary** operator
in the language

Expressions in C

Basic rules for expressions

- Unary operators are performed from right to left.

`&*p ~-v *f()`

- Binary operators are performed in accordance with their preferences.

`a[i] + b * *p`

- Binary operators of the same preference are performed from left to right.

`x + y - z`

`a[i] = b = c + d*e`

- The **side effect** of the expression (if any) happens after both operands are evaluated.

`a[i++] = i`

- Parentheses are used to change the default execution order.

`(a[i] + b) * *p`

Expressions in C

Some examples for the comma operator

```
if ( f(b),g(c) )  
    ...  
else  
    ...
```

```
for ( int i=0, j=0; i<10 && j<10; i++, j++)  
{  
    Some calculations on a matrix...  
}
```

Expressions in C

Some more examples 😊.

- Suppose `p1` and `p2` are pointers.

```
while (*p1++ = *p2++) ;
```

Expressions in C

Some more examples 😊.

- Suppose `p1` and `p2` are pointers.

```
while (*p1++ = *p2++) ;
```

This is the empty
("null") statement

- This is the while loop.
- The construct within parentheses is the expression that specifies the loop condition: whether to continue executing loop body or to exit the loop.
- The body of the loop contains only one statement: this is empty statement. It doesn't perform any actions.
- Therefore, all useful actions are within the loop header.

Expressions in C

Some more examples 😊.

- Suppose `p1` and `p2` are pointers.

```
while (*p1++ = *p2++) ;
```

The loop performs **copying** elements of one array/string to another until the element of value 0 is encountered.

This is the empty ("null") statement

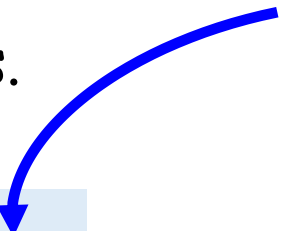
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Expressions in C

Some more examples 😊.

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while (*p1++ = *p2++) ;
```



The loop performs **copying** elements of one array/string to another until the element of value 0 is encountered.

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while (*p1++ == *p2++) ;
```

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Expressions in C

Some more examples 😊.

- Suppose `p1` and `p2` are pointers.

```
while (*p1++ = *p2++) ;
```

The loop performs **copying** elements of one array/string to another until the element of value 0 is encountered.

```
while (*p1++ == *p2++) ;
```

The loop performs **comparison** elements of one array/string with corresponding elements of another. The loop stops when the first pair of non-equal elements is encountered.

This is the empty ("null") statement

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Conclusion: What We Have Learnt Today

- Dynamic memory management
- Statements;
Declaration statements
- Expressions;
Expression statements