

CS100 Lecture 4

Operators and Control Flow II, Functions

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Operators

Operator precedence

Operator precedence defines the order in which operators are bound to their arguments.

Example: `*` and `/` have higher precedence than `+` and `-`, so `a + b * c` is interpreted as `a + (b * c)` instead of `(a + b) * c`.

Operator precedence does not determine evaluation order.

- `f() + g() * h()` is interpreted as `f() + (g() * h())`, but the order in which `f`, `g` and `h` are called is unspecified.

Associativity

Each operator is either **left-associative** or **right-associative**.

Operators with the same precedence have the same associativity.

Example: `+` and `-` are **left-associative**, so `a - b + c` is interpreted as `(a - b) + c`, instead of `a - (b + c)`.

Associativity does not determine **evaluation order**.

- `f() - g() + h()` is interpreted as `(f() - g()) + h()`, but the order in which `f`, `g` and `h` are called is **unspecified**.

Evaluation order

Unless otherwise stated, the order in which the operands are evaluated is **unspecified**.

- We will see that `&&`, `||` and `?:` (and also `,`, in recitations) have specified evaluation order of their operands.

Examples: In the following expressions, it is **unspecified** whether `f` is called before `g`.

- `f() + g()`
- `f() == g()`
- `some_function(f(), g())` (Note that the `,` here is not the [comma operator](#).)
- ...

Evaluation order and undefined behavior

Let `A` and `B` be two expressions. The behavior is undefined if

- the order in which `A` and `B` are evaluated is unspecified, and
- both `A` and `B` modify an object, or one modifies an object and the other uses its value.

Examples:

```
i = ++i + i++; // undefined behavior
i = i++ + 1;   // undefined behavior
printf("%d, %d\n", i, i++); // undefined behavior
```

Recall that **undefined behavior** means "everything is possible". We cannot make any assumptions about the behavior of the program.

Terminology: Return type/value of an operator

When it comes to "the return type/value of an operator", we are actually viewing the operator as a function:

```
int operator_plus(int a, int b) {  
    return a + b;  
}  
int operator_postfix_inc(int &x) { // We must use a C++ notation here.  
    int old = x;  
    x += 1;  
    return old;  
}
```

The "return value" of an operator is the value of the expression it forms.

The "return type" of an operator is the type of its return value.

Comparison operators

Comparison operators are binary operators that test a condition and return `1` if that condition is logically **true** and `0` if it is logically **false**.

Operator	Operator name
<code>a == b</code>	equal to
<code>a != b</code>	not equal to
<code>a < b</code>	less than

Operator	Operator name
<code>a > b</code>	greater than
<code>a <= b</code>	less than or equal to
<code>a >= b</code>	greater than or equal to

For most cases, the operands `a` and `b` are also converted to a same type, just as what happens for `a + b`, `a - b`, ...

Comparison operators

Note: Comparison operators in C **cannot be chained**.

Example: `a < b < c` is interpreted as `(a < b) < c` (due to left-associativity), which means to

- compare `(a < b)` first, whose result is either `0` or `1`, and then
- compare `0 < c` or `1 < c`.

To test $a < b < c$, use `a < c && b < c`.

Logical operators

Logical operators apply standard boolean algebra operations to their operands.

Operator	Operator name	Example
!	logical NOT	!a
&&	logical AND	a && b
	logical OR	a b

Logical operators

`!a` , `a && b` , `a || b`

Recall the boolean algebra:

A	B	$\neg A$	$A \wedge B$	$A \vee B$
True	True	False	True	True
True	False	False	False	True
False	True	True	False	True
False	False	True	False	False

For C logical operators:

<code>a</code>	<code>b</code>	<code>!a</code>	<code>a && b</code>	<code>a b</code>
<code>!= 0</code>	<code>!= 0</code>	<code>0</code>	<code>1</code>	<code>1</code>
<code>!= 0</code>	<code>== 0</code>	<code>0</code>	<code>0</code>	<code>1</code>
<code>== 0</code>	<code>!= 0</code>	<code>1</code>	<code>0</code>	<code>1</code>
<code>== 0</code>	<code>== 0</code>	<code>1</code>	<code>0</code>	<code>0</code>

Logical operators

Precedence: `!` > comparison operators > `&&` > `||`.

Typical example: lexicographical comparison of two pairs (a_1, b_1) and (a_2, b_2)

```
int less(int a1, int b1, int a2, int b2) {  
    return a1 < b1 || (a1 == b1 && a2 < b2);  
}
```

The parentheses are optional here, but it improves readability.

Avoid abuse of parentheses

Too many parentheses **reduce** readability:

```
int less(int a1, int b1, int a2, int b2) {  
    return (((a1) < (b1)) || (((a1) == (b1)) && ((a2) < (b2))));  
    // Is this a1 < b1 || (a1 == b1 && a2 < b2)  
    //      or (a1 < b1 || a1 == b1) && a2 < b2 ?  
}
```

[Best practice] Use one pair of parentheses when two binary logical operators meet.

Short-circuit evaluation

`a && b` and `a || b` perform **short-circuit evaluation**:

- For `a && b`, `a` is evaluated first. If `a` compares equal to zero (is logically **false**), `b` is not evaluated.
 - $\text{False} \wedge p \equiv \text{False}$
- For `a || b`, `a` is evaluated first. If `a` compares not equal to zero (is logically **true**), `b` is not evaluated.
 - $\text{True} \vee p \equiv \text{True}$

The evaluation order is specified!

Conditional operator `?:`

Syntax: `condition ? expressionT : expressionF`,

where `condition` is an expression of scalar type.

The evaluation order is specified!

- First, `condition` is evaluated.
- If `condition` compares not equal to zero (is logically **true**), `expressionT` is evaluated, and the result is the value of `expressionT`.
- Otherwise (if `condition` compares equal to zero, which is logically **false**), `expressionF` is evaluated, and the result is the value of `expressionF`.

Conditional operator `?:`

Syntax: `condition ? expressionT : expressionF`,

Example: `to_uppercase(c)` returns the uppercase form of `c` if `c` is a lowercase letter, or `c` itself if it is not.

```
char to_uppercase(char c) {  
    if (c >= 'a' && c <= 'z')  
        return c - ('a' - 'A');  
    else  
        return c;  
}
```

Use `?:` to rewrite it:

```
char to_uppercase(char c) {  
    return c >= 'a' && c <= 'z' ? c - ('a' - 'A') : c;  
}
```

Conditional operator `?:`

Syntax: `condition ? expressionT : expressionF`

Use it to replace some simple and short `if - else` statement.

Avoid abusing it! Nested conditional operators reduces readability significantly.

```
int result = a < b ? (a < c ? a : c) : (b < c ? b : c); // Um ...
```

[Best practice] Avoid more than two levels of nested conditional operators.

Assignment operator =

```
lhs = rhs
```

The assignment operator **returns the value of** `lhs` **after assignment.**

Moreover, the assignment operator is **right-associative**, making it possible to write "chained" assignments:

```
int a = 0, b = 1, c = 2;  
a = b = c; // interpreted as a = (b = c)  
           // Both a and b are assigned with 2.
```

Control Flow

do - while

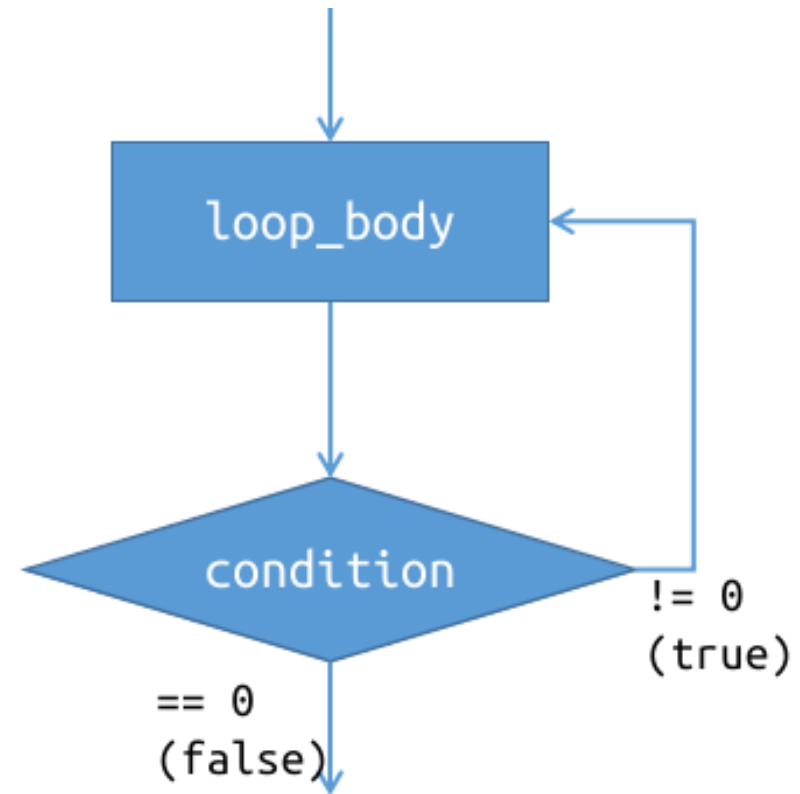
Syntax: `do loop_body while (condition);`

Executes `loop_body` repeatedly until the value of `condition` compares equal to zero (is logically **false**).

Example:

```
int i = 0;  
do {  
    printf("%d", i++);  
} while (i < 5);
```

Output: 01234



do - while

Note that in each iteration, the condition is tested **after** the body is executed.

```
int i = 0;  
do {  
    printf("%d", i++);  
} while (i < n);
```

Even if `n == 0`, `0` is printed. The loop body is always executed at least once.

do - while

Exercise: Rewrite a `do - while` loop using a `while` loop.

```
do {  
    // loop_body  
} while (condition);
```

do - while

Exercise: Rewrite a `do - while` loop using a `while` loop.

```
do {  
    // loop_body  
} while (condition);
```

Use `while (1)` and `break`:

```
while (1) {  
    // loop_body  
    if (!condition)  
        break;  
}
```


switch - case

The calculator example:

```
int main(void) {  
    double a, b;  
    char op;  
    scanf("%lf %c %lf", &a, &op, &b);  
    if (op == '+')  
        printf("%lf\n", a + b);  
    else if (op == '-')  
        printf("%lf\n", a - b);  
    else if (op == '*')  
        printf("%lf\n", a * b);  
    else if (op == '/')  
        printf("%lf\n", a / b);  
    else  
        printf("Invalid operator!\n");  
    return 0;  
}
```

switch - case

Rewrite it using `switch - case` :

```
if (op == '+')
    printf("%lf\n", a + b);
else if (op == '-')
    printf("%lf\n", a - b);
else if (op == '*')
    printf("%lf\n", a * b);
else if (op == '/')
    printf("%lf\n", a / b);
else
    printf("Invalid operator: %c\n", op);
```

```
switch (op) {
case '+':
    printf("%lf\n", a + b); break;
case '-':
    printf("%lf\n", a - b); break;
case '*':
    printf("%lf\n", a * b); break;
case '/':
    printf("%lf\n", a / b); break;
default:
    printf("Invalid operator!\n");
    break;
}
```

switch - case

```
switch (expression) { ... }
```

```
switch (op) {  
  case '+':  
    printf("%lf\n", a + b); break;  
  case '-':  
    printf("%lf\n", a - b); break;  
  case '*':  
    printf("%lf\n", a * b); break;  
  case '/':  
    printf("%lf\n", a / b); break;  
  default:  
    printf("Invalid operator!\n");  
    break;  
}
```

- First, `expression` is evaluated.
- Control finds the `case` label to which `expression` compares equal, and then goes to that label.
- Starting from the selected label, **all subsequent statements are executed until a `break;` or the end of the `switch` statement is reached.**
- Note that `break;` here has a special meaning.

switch - case

```
switch (expression) { ... }
```

```
switch (op) {  
  case '+':  
    printf("%lf\n", a + b); break;  
  case '-':  
    printf("%lf\n", a - b); break;  
  case '*':  
    printf("%lf\n", a * b); break;  
  case '/':  
    printf("%lf\n", a / b); break;  
  default:  
    printf("Invalid operator!\n");  
    break;  
}
```

- If no `case` label is selected and `default:` is present, the control goes to the `default:` label.
- `default:` is optional, and often appears in the end, though not necessarily.
- `break;` is often needed. Modern compilers often warn against a missing `break;`.

switch - case

The expression in a `case` label must be an integer *constant expression*, whose value is known at compile-time, such as `42`, `'a'`, `true`, ...

```
int n; scanf("%d", &n);
int x = 42;
switch (value) {
    case 3.14: // Error: It must have an integer type.
        printf("It is pi.\n");
    case n:    // Error: It must be a constant expression (known at compile-time)
        printf("It is equal to n.\n");
    case 42:   // OK.
        printf("It is equal to 42.\n");
    case x:    // Error: `x` is a variable, not treated as "constant expression".
        printf("It is equal to x.\n");
}
```

switch - case

Another example: Determine whether a letter is vowel or consonant.

```
switch (letter) {  
    case 'a':  
    case 'e':  
    case 'i':  
    case 'o':  
    case 'u':  
        printf("%c is vowel.\n", letter);  
        break;  
    default:  
        printf("%c is consonant.\n", letter);  
}
```

Functions

Call and return

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

double divide(int a, int b) {
    if (b == 0) {
        fprintf(stderr, "Division by zero!\n");
        exit(EXIT_FAILURE);
    }
    return 1.0 * a / b;
}

int main(void) {
    int x, y; scanf("%d%d", &x, &y);
    double result = divide(x, y);
    printf("%lf\n", result);
    // ...
}
```

- For the *call expression* `divide(x, y)` :
First the arguments `x` and `y` are passed into `divide` as if the parameters are initialized as follows:

```
int a = x;
int b = y;
```

Then control is transferred into the function `divide`, starting from the first statement.

Call and return

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

double divide(int a, int b) {
    if (b == 0) {
        fprintf(stderr, "Division by zero!\n");
        exit(EXIT_FAILURE);
    }
    return 1.0 * a / b;
}

int main(void) {
    int x, y; scanf("%d%d", &x, &y);
    double result = divide(x, y);
    printf("%lf\n", result);
    // ...
}
```

`return` does two things:

- passes a value out to the *call site*.
 - This value is the result of the **call expression**.
 - Such a value does not exist if the function return type is `void`.
- transfers the control to the *call site*.

Call and return

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

double divide(int a, int b) {
    if (b == 0) {
        fprintf(stderr, "Division by zero!\n");
        exit(EXIT_FAILURE);
    }
    return 1.0 * a / b;
}

int main(void) {
    int x, y; scanf("%d%d", &x, &y);
    double result = divide(x, y);
    printf("%lf\n", result);
    // ...
}
```

- The parentheses `()` in the expression `divide(x, y)` is the **function-call operator**.
- Even if the function accepts no parameters, the function-call operator should not be omitted.
- A statement like `f;` without the function-call operator is **valid**.
 - It is a statement that has no effect, just like `5;`, `2+3;`, `;` or `{}`.

Call and return

If a function has return type `void`, the function does not pass a value to the call site.

For a non-`void` function:

- A `return something;` statement must be executed to return something.
- If control reaches the end of the function without a `return` statement, the return value is undefined. **The behavior is undefined** if such value is used.

```
int do_something(int i) {  
    printf("%d\n", i);  
}
```

```
a.c: In function 'do_something':  
a.c:5:1: warning: control reaches end of non-void function [-Wreturn-type]  
    5 | }
```

[Best practice] Avoid unnecessary_if

```
int abs_int(int x) {  
    if (x < 0)  
        return -x;  
    else if (x == 0)  
        return 0;  
    else if (x > 0)  
        return x;  
}
```

```
a.c: In function abs_int:  
a.c:8:1: warning: control reaches end of non-void function [-Wreturn-type]  
      8 | }
```

[Best practice] Avoid unnecessary `if`

The last `if (x > 0)` is not needed:

```
int abs_int(int x) {  
    if (x < 0)  
        return -x;  
    else if (x == 0)  
        return 0;  
    else // x > 0 must hold. No need to test it  
        return x;  
}
```

It can be simplified as

```
int abs_int(int x) {  
    return x < 0 ? -x : x;  
}
```

Function declaration and definition

A **definition** of a function contains the function body.

```
int sum(int a, int b) {  
    return a + b;  
}
```

A **declaration** of a function contains only its return type, its name and the types of its parameters, ended with `;`.

The following statements declare **the same function**:

```
int sum(int, int);  
int sum(int x, int y);  
int sum(int a, int);
```

Function declaration and definition

- A function should have only one definition, but can be declared many times.
- A definition is also a declaration, since it contains all the information that a declaration has.
- When a function is called, its declaration must be present.

```
int sum(int, int);    // declares the function
int main(void) {
    int x = sum(2, 3);    // ok
}
int sum(int x, int y) { // gives its definition afterwards
    return x + y;
}
```

Scope

```
int add(int x, int y) {  
    return x + y;  
}  
int square(int x) {  
    return x * x;  
}  
int main(void) {  
    int x; scanf("%d", &x);  
    printf("%d\n", square(x));  
    if (x == 42) {  
        int x = 35;  
        printf("%d\n", square(square(x)));  
    }  
    for (int x = 1; x <= 10; ++x)  
        printf("%d\n", square(x + 1));  
    return 0;  
}
```

- The scopes form a tree structure:

- ```
global---add
 | -square
 | -main---if
 | -for
```



# Name lookup

```
int add(int x, int y) {
 return x + y;
}

int square(int x) {
 return x * x;
}

int main(void) {
 int x; scanf("%d", &x);
 printf("%d\n", square(x));
 if (x == 42) {
 int x = 35;
 printf("%d\n", square(square(x)));
 }
 for (int x = 1; x <= 10; ++x)
 printf("%d\n", square(x + 1));
 return 0;
}
```

- The scopes form a tree structure:

```
global---add
 |-square
 |-main---if
 |-for
```

- When a name `x` is referenced, the **name lookup** for `x` is performed:
  - Only the declarations before the current position can be seen.
  - Lookup is performed from the innermost scope to the outer scopes, until a declaration is found.

# Name lookup

```
int add(int x, int y) {
 return x + y;
}

int square(int x) {
 return x * x;
}

int main(void) {
 int x; scanf("%d", &x);
 printf("%d\n", square(x));
 if (x == 42) {
 int x = 35;
 printf("%d\n", square(square(x)));
 }
 for (int x = 1; x <= 10; ++x)
 printf("%d\n", square(x + 1));
 return 0;
}
```

- The scopes form a tree structure:
- ```
global---add  
      |---square  
      |---main---if  
                |---for
```
- A declaration in an inner scope may hide a declaration in an outer scope that introduces the same name.
- If two declarations in a same scope introduce a same name, the program is ill-formed. ¹

Scopes and name lookup

[Best practice] Declare a variable right before the use of it. Declare it in a scope as small as possible.

[Best practice] Don't worry about the same names in different scopes.

```
// The three `i`'s are local to the three loops. They will not collide.  
for (int i = 0; i < n; ++i)  
    do_something(i);  
for (int i = 0; i < n; ++i)  
    do_another_thing(i);  
if (condition()) {  
    for (int i = 0; i < n; ++i)  
        do_something_else(i);  
}
```

Exercise

Write a function `yes_or_no` that asks if the user agrees (`Y / y` , `N / n`). Repeat until the input is valid. Returns `1` if the user agrees, `0` otherwise.

```
int main(void) {  
    int response = yes_or_no();  
    if (response)  
        printf("Your response is yes.\n");  
    else  
        printf("Your response is no.\n");  
    return 0;  
}
```

Summary