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
`a == b`	equal to
`a != b`	not equal to
`a < b`	less than

Operator	Operator name
`a > b`	greater than
`a <= b`	less than or equal to
`a >= b`	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	$\neg A$	$A \land B$	$A \lor B$
True	True	False	True	True
True	False	False	False	True
False	True	True	False	True
False	False	True	False	False

For C logical operators:

`a`	`b`	`!a`	`a && b`	`a || b`
`!= 0`	`!= 0`	`0`	`1`	`1`
`!= 0`	`== 0`	`0`	`0`	`1`
`== 0`	`!= 0`	`1`	`0`	`1`
`== 0`	`== 0`	`1`	`0`	`0`

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

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.

Control Flow

`do`-`while`

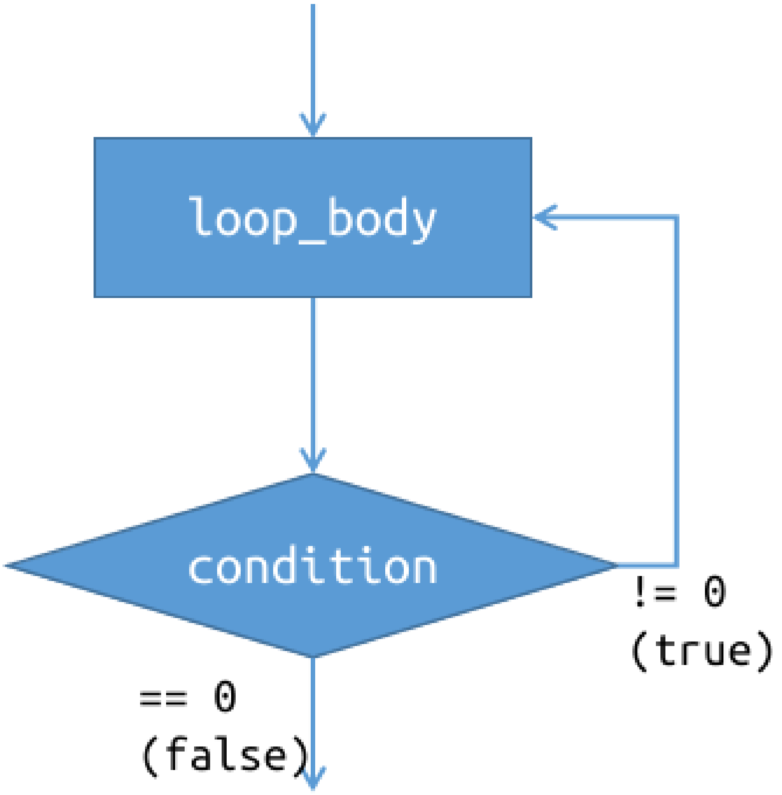
Syntax: `do loop_body while (condition);`

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.

```c
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:

```c
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`:

```c
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);
```

```c
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`, ...

```c
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