

C Programming

Lecture 10: Bitwise Operations

$$\begin{array}{r} 00111100 \\ \oplus 00001101 \\ \hline 11001110 = 206_{(10)} \end{array}$$

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- 1 Bitwise operations
- 2 Applications of Bitwise operations

What are bit operations?

- Data inside computers are kept in binary form, such as 10101111
- One binary code is a data item, it could be an integer, a float number, or a string
- In some scenarios, we need to operate them bit-wisely
- Given a binary code 10101111
- How could we extract out its lower 4 bits

The bitwise operators

- There are 6 bit operators
- bit **and** &
- bit **or** |
- bit **xor** ^
- bit **not** ~
- **left shift** <<
- **right shift** >>

Truth tables for $\&$, $|$ and \wedge

c1	c2	c1 & c2
1	1	1
1	0	0
0	1	0
0	0	0

c1	c2	c1 c2
1	1	1
1	0	1
0	1	1
0	0	0

c1	c2	c1 ^ c2
1	1	0
1	0	1
0	1	1
0	0	0

- Notice that it is applied on one bit ONLY
- If there are multiple bits, the operator is applied on each bit
- The result of one bit operation has **NO** impact on the other bit

AND & and OR |

- Given two variables $a = 60$ and $b = 13$ of **unsigned char**
- See what are the result for **$a \& b$**
- See what are the result for **$a | b$**

$$\begin{array}{r} 00111100 \\ \& 00001101 \\ \hline 00001100 = 12_{(10)} \end{array}$$

$$\begin{array}{r} 00111100 \\ | 00001101 \\ \hline 00111101 = 61_{(10)} \end{array}$$

```
1 #include <stdio.h>
2 int main(){
3     unsigned char a = 60, b = 13;
4     unsigned char c = a & b;
5     unsigned char d = a | b;
6     printf("c=%d, d=%d\n", c, d);
7     return 0;
8 }
```

OR | and XOR ^

- Given two variables $a = 60$ and $b = 13$ of **unsigned char**
- See what are the result for $a | b$
- See what are the result for $a ^ b$

$$\begin{array}{r} 00111100 \\ | \quad 00001101 \\ \hline 00111101 = 61_{(10)} \end{array}$$

$$\begin{array}{r} 00111100 \\ ^ \quad 00001101 \\ \hline 00110001 = 49_{(10)} \end{array}$$

```
1 #include <stdio.h>
2 int main(){
3     unsigned char a = 60, b = 13;
4     unsigned char c = a | b;
5     unsigned char d = a ^ b;
6     printf("c=%d, d=%d\n", c, d);
7     return 0;
8 }
```

NOT \sim (1)

c1	\sim c1
1	0
0	1

- Flip a bit
- $1 \rightarrow 0, 0 \rightarrow 1$
- The result of one bit operation has **NO** impact on the other bit

NOT ~ (2)

- Given one variable $a = 60$ of **unsigned char**
- See what are the result for $\sim a$

$$\begin{array}{r} \sim 00111100 \\ \hline 11000011 = 195_{(10)} \end{array}$$

```
1 #include <stdio.h>
2 int main(){
3     unsigned char a = 60;
4     unsigned char c = ~a;
5     unsigned char d = !a;
6     printf("c=%d, d=%d\n", c, d);
7     return 0;
8 }
```

Example-1: implement \odot operation (1)

c1	c2	$c1 \odot c2$
1	1	1
1	0	0
0	1	0
0	0	1

- In some cases, we need **1** for bits of the same, while **0** for bit of difference
- There is **NO** such operator in C
- Can we realize it with provided operators?

Think about it in five minutes...

Example-1: implement \odot operation (2)

$$\begin{array}{rcl} \begin{array}{r} 00111100 \\ \odot \quad 00001101 \\ \hline \end{array} & \Rightarrow & \begin{array}{r} \text{Step 1.} \\ \sim 00111100 \\ \hline 11000011 \end{array} \end{array} \quad \begin{array}{rcl} \begin{array}{r} \text{Step 2.} \\ 11000011 \\ \wedge \quad 00001101 \\ \hline 11001110 \\ 00110001 \end{array} & \begin{array}{l} \text{---} \\ \text{---} \end{array} & \begin{array}{l} \\ \\ 206_{(10)} \\ 49_{(10)} \end{array} \end{array}$$

- We achieve this in two steps
 - 1 Flip one of the numbers
 - 2 Apply **XOR** between the flipped number and another number

Example-1: implement \odot operation (3)

Step 1. Step 2.

$$\begin{array}{rcl} \begin{array}{r} 00111100 \\ \odot \quad 00001101 \\ \hline \end{array} & \Rightarrow & \begin{array}{r} \sim \quad 00111100 \\ \hline 11000011 \end{array} \end{array}$$

A green arrow points from the result of Step 1 to the XOR operation in Step 2.

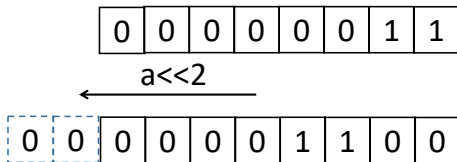
$$\begin{array}{rcl} & & \begin{array}{r} 11000011 \\ \wedge \quad 00001101 \\ \hline 11001110 \\ 00110001 \end{array} \end{array}$$

$11001110 = 206_{(10)}$
 $00110001 = 49_{(10)}$

```
1 #include <stdio.h>
2 int main(){
3     unsigned char a = 60, b = 13;
4     unsigned char c = ~a;
5     unsigned char d = c ^ b;
6     printf("c=%d, d=%d\n", c, d);
7     return 0;
8 }
```

- You will get the same result if you flip b

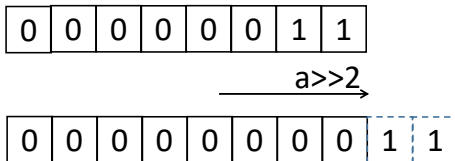
Left shift $val \ll numb$



- Shift the binary code towards the left in **numb** bits
- Append the lower bits with **0**s
- For example, $a = 3$; $a \ll 2$
- The result is **12**

```
1 #include <stdio.h>
2 int main(){
3     unsigned char a = 3, b = 0;
4     b = a << 2;
5     printf("a = %d, b = %d\n", a, b);
6     return 0;
7 }
```

Right shift $val \gg numb$



- Shift the binary code towards the right in **numb** bits
- Append the higher bits with **0**s
- For example, $a = 3$; $a \gg 2$
- The result is **0**

```
1 #include <stdio.h>
2 int main() {
3     unsigned char a = 3, b = 10, c = 0;
4     b = a >> 2;
5     c = a >> 1;
6     printf("a=%d, b=%d, c=%d\n", a, b, c);
7     return 0;
8 }
```

- 1 Bitwise operations
- 2 Applications of Bitwise operations

Example-2: extract out specified bits from a number (1)

- Given a binary code 10101110
- How could we extract out its higher 4 bits
- Given `int a=0xAE`

Think about it in five minutes....

Example-2: extract out specified bits from a number (2)

- How could we extract out its **higher 4 bits**
- Given `int a=0xAE`
- We introduce a template number `b = 0xF0`

Try this operation: `a & b`

Example-2: extract out specified bits from a number (3)

- How could we extract out its **higher 4 bits**
- Given `int a=0xAE`
- We introduce a template number `b = 0xF0`

```
1 #include <stdio.h>
2 int main(){
3     unsigned char a = 0xAE, b = 0xF0, c = 0;
4     c = a & b;
5     c = c>>4;
6     printf("a=%0x, c=%0x\n", a, c);
7     return 0;
8 }
```

Example-3: check whether a number is odd (1)

- Given a number **n**, we want to know whether it is odd or even
- We check **$n \% 2 \neq 1$**
- Now we have another option
- We only need to check the last bit of an integer number
 - ① If it is **1**, it is odd
 - ② Otherwise, it is even

Example-3: check whether a number is odd (2)

- Given a number **n**, we want to know whether it is odd or even
- We check **$n \% 2 \neq 1$**
- Now we have another option

```
1 #include <stdio.h>
2 int main(){
3     int a = 7;
4     scanf("%d", &a);
5     if( a & 1)
6         printf(" It _is _odd\n");
7     else
8         printf(" It _is _even\n");
9     return 0;
10 }
```

Example-4: count how many bits is 1 (1)

- Given an integer number **n**, we want to know how many bits is '1'
- We shift the number to right one bit at once
- We check whether the last bit of the shifted number is '1'
 - ① If it is 1, counted in
 - ② Otherwise, do nothing

Example-4: count how many bits is 1 (1)

- We shift the number to right one bit at once
- We check whether the last bit of the shifted number is '1'
 - ① If it is 1, counted in
 - ② Otherwise, do nothing

```
1 #include <stdio.h>
2 int main(){
3     int a = 11, count = 0, b = 0;
4     scanf("%d", &a);
5     while(a>0){
6         b = a & 1;
7         if(b == 1){
8             count++;
9         }
10        a = a >> 1;
11    }
12    printf("count = %d\n", count);
13    return 0;
14 }
```

Example-5: set the k-th bit to 1 (1)

- Given a number **n**=01010000
- We want to set the 4-th bit to 1
 - ① We left shift 1 3 times
 - ② Perform OR between n and the shifted number

Example-5: set the k-th bit to 1 (2)

- Given a number **n=01010000**
- We want to set the 4-th bit to **1**
 - We left shift **1** 3 times
 - Perform OR between n and the shifted number

```
1 #include <stdio.h>
2 int main(){
3     int a = 0x50, b = 0;
4     b = 1 << 3;
5     a = a | b;
6     printf("count = %x\n", a);
7     return 0;
8 }
```