C Programming
Lecture 10: Bitwise Operations

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Autumn Semester 2022

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Outline

What are bit operations?

- Data onside 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 $\ll$
- right shift $\gg$

Truth tables for &, | and ^

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

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

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

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

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

$$
\begin{array}{rr}
 & 00111100 \\
| & 00001101 \\
\hline
 & 00111101
\end{array} = 61_{(10)}
\qquad
\begin{array}{rr}
 & 00111100 \\
\wedge & 00001101 \\
\hline
 & 00110001
\end{array} = 49_{(10)}
$$

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

NOT ~ (1)

c1	~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 ~a

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

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

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)

$$\begin{array}{r} \sim\ 00111100 \\ \hline 11000011 \end{array}$$

$$\begin{array}{rrl} & 11000011 & \\ \wedge & 00001101 & \\ \hline & 11001110 & = 206_{(10)} \\ & 00110001 & = 49_{(10)} \end{array}$$

- 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 ⊙ operation (3)

```
~ 00111100
-----------
  11000011
```

```
  11000011
^ 00001101
-----------
  11001110
  00110001
```

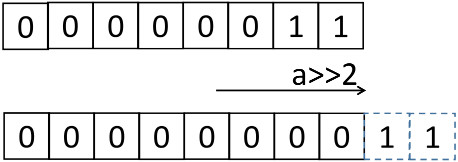
$11001110 = 206_{(10)}$

$00110001 = 49_{(10)}$

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

- You will get the same result if you flip b

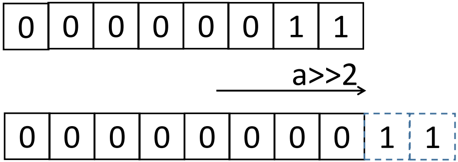
Left shift $val \ll numb$



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

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

Right shift *val*≫*numb*



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

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

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

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

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** $!= 1$
- 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** != 1
- Now we have another option

```
#include <stdio.h>
int main(){
   int a = 7;
   scanf("%d", &a);
   if( a & 1)
         printf("It is odd\n");
     else
         printf("It is even\n");
   return 0;
}
```

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

```
#include <stdio.h>
int main(){
   int a = 11, count = 0, b = 0;
   scanf("%d", &a);
   while(a>0){
       b = a & 1;
       if(b == 1){
            count++;
       }
       a = a >> 1;
   }
   printf("count = %d\n", count);
   return 0;
}
```

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
  1. We left shift 1 3 times
  2. Perform OR between n and the shifted number

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