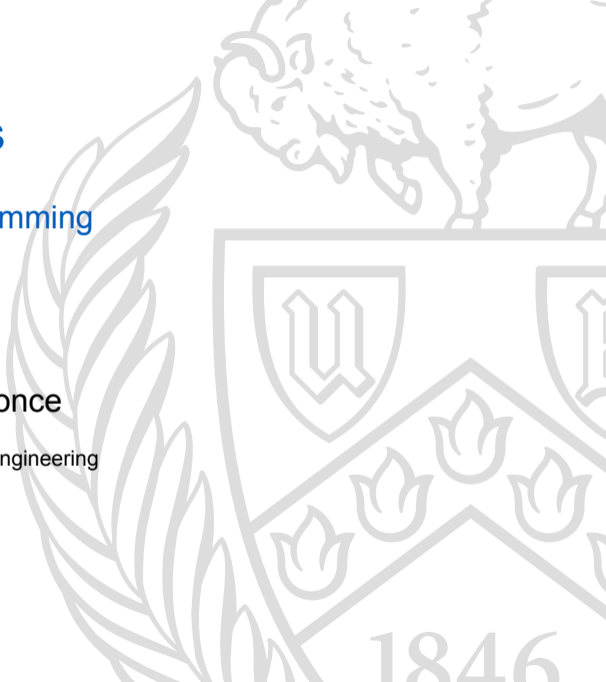


Bitwise Operations

CSE 220: Systems Programming

Ethan Blanton & Carl Alphonse

Department of Computer Science and Engineering
University at Buffalo



Planning: Diagrams

After a once-through of the documentation, **start drawing**.

(See the PA2 Handout video!)

Draw **the ideas**:

- Data structures
 - Abstract the structure!
 - Arrows represent connections
 - Boxes represent data storage
 - ...
- Program flow
 - Read args → open inputs → ...
 - (This is more interesting if it's non-linear!)

Planning: Pseudocode

After diagrams, **write pseudocode**.

You can write it at a very high level:
“For every cell in the matrix”

Then **put it in your code as comments**.

Augment the comments with code as you develop!

```
// For every cell in the matrix  
//   Compute neighbors
```

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You can write it at a very high level:
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Then **put it in your code as comments**.

Augment the comments with code as you develop!

```
// For every cell in the matrix
for (int y = 0; y < GRIDY; y++) {
    for (int x = 0; x < GRIDX; x++) {
        // Compute neighbors
    }
}
```

Bitwise Operations

We have seen **arithmetic** and **logical** integer operations.

C also supports **bitwise** operations.

These operations correspond to **circuit elements**.

They are often related to, yet **different from**, logical operations.

The major operations are:

- Bitwise complement
- Bit shifts (left and right)
- Bitwise AND, OR, and XOR

Truth Tables

You should already be familiar with [truth tables](#).

Every bitwise operation (except shift) is defined by a truth table.

A truth table represents [one or two input bits](#) and their [output bit](#).

For example, [bitwise OR](#):

x	y	Result
0	0	0
1	0	1
0	1	1
1	1	1

Bitwise Operations

OR (\vee):

x	y	Result
0	0	0
1	0	1
0	1	1
1	1	1

XOR (\oplus):

x	y	Result
0	0	0
1	0	1
0	1	1
1	1	0

AND (\wedge):

x	y	Result
0	0	0
1	0	0
0	1	0
1	1	1

NOT (\neg):

x	Result
0	1
1	0

Bit Operations on Words

Each of these bit operations can be applied to any **integer type**.

Each **bit position** will have the operation applied individually.

E.g., the application of XOR to an n-bit word is:

$$\forall_{i=0}^{n-1} \text{Result}_i = x_i \oplus y_i$$

Each operation applies to a **single bit**, so no carries are needed.

Operators

The C bitwise operators divide into **unary** and **binary** operators:

Unary:

- $\sim x$: Bitwise complement of x ($0 \rightarrow 1, 1 \rightarrow 0$)

Binary:

- $x \mid y$: Bitwise OR of x and y
- $x \& y$: Bitwise AND of x and y
- $x \wedge y$: Bitwise XOR of x and y
- $x \ll y$: Left shift x by y bits
- $x \gg y$: Right shift x by y bits

Bit Shifting

Bit shifts are slightly more complicated.

C can shift bits left or right.

- Left shift (\ll): bits move toward larger bit values
- Right shift (\gg): bits move toward smaller bit values

For left shift, zeroes are shifted in on the right.

Examples:

0111 left shift 1 bit \rightarrow 1110

0010 left shift 2 bits \rightarrow 1000

Right Shifts

Right shifts are somewhat trickier.

In particular, they may obey sign extension.

If the shifted integer is unsigned, zeroes are shifted in on the left:

0110 right shift 1 bit → 0011

1010 right shift 2 bits → 0010

If the shifted integer is signed, the sign bit may affect the shift.

- If it is zero, shifts behave as unsigned
- If it is one, it might shift in ones

If [the shifted value] is a signed type and a negative value, the resulting value is implementation-defined. — ISO C99

Bit versus Logical Operators

Do not confuse the bit and logical operators!

Some of them work correctly for integers; e.g., `|`.

Some decidedly do not, e.g., `&`:

`1 & 2` → logical false!

Not (`~`) and and (`&`) are particularly pernicious because they often work.

Masking

Many bitwise operations are used to work on a **portion** of a word.

This typically requires **masking** either:

- The bits to be modified
- The bits to be ignored

Masking uses `&` and sometimes `~`.

For example, to get the **lowest 8 bits** of an integer:

```
eightbits = x & 0xff;
```

(You might remember this from `dumpmem()`.)

Bit Twiddling

Setting and unsetting **individual bits** typically uses masking.

Assume we want to **set bit zero**:

```
#define LOWBIT 0x1
```

```
x = x | LOWBIT;
```

Later, we want to **unset bit zero**:

```
x = x & ~LOWBIT;
```

In this case, `~LOWBIT` is a mask for **all bits except 0**.

Twiddling with XOR

If you always want to **complement** a bit, you can use XOR.

This comes from the truth table; assume y is a constant 1:

x	y	Result
0	0	0
1	0	1
0	1	1
1	1	0

```
x = x ^ LOWBIT;
```

Shifting and Powers of 2

Note that **bit shifting left** is multiplying by powers of 2!

A one-bit left shift is multiplying by 2:

0010 \rightarrow 2

0100 \rightarrow 4

0011 \rightarrow 3

0110 \rightarrow 6

Successive bit shifts continue to multiply by 2.

1 ($= 2^0$)

1 \ll k ($= 2^k$)

Forcing Endianness

```
int htonl(int input) {
    int output;
    char *outb = (char *)&output;
    for (int b = 0; b < sizeof(int); b++) {
        int shift = (sizeof(int) - b - 1) * 8;
        outb[b] = (input >> shift) & 0xff;
    }
    return output;
}
```

htonl in Action

```
int x = 0x01020304;  
int y = htonl(x);  
  
dump_mem(&x, sizeof(x));  
dump_mem(&y, sizeof(y));
```

```
04 03 02 01  
01 02 03 04
```

Summary

- C can manipulate **individual bits** in memory.
- Bit operations can be **subtle and tricky!**
- **Signedness** matters.
- Bit manipulations can **force endianness** or other representations.

References I

Required Readings

- [2] Brian W. Kernighan and Dennis M. Ritchie. *The C Programming Language*. Second Edition. Chapter 2: 2.9; Appendix A: A7.4.6, A7.8, A7.11–A7.13. Prentice Hall, 1988.
- [3] Ian Weinand. *Computer Science from the Bottom Up*. Chapter 2, part 1: 1.1.4, 1.1.5, 1.3. URL: <https://www.bottomupcs.com/index.html>.

Optional Readings

- [1] Randal E. Bryant and David R. O'Hallaron. *Computer Science: A Programmer's Perspective*. Third Edition. Chapter 2: 2.1.6–2.1.9. Pearson, 2016.

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