Bitwise Operations

CSE 220: Systems Programming

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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:

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
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</tr>
</tbody>
</table>
## Bitwise Operations

### OR (∨):

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
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<td>1</td>
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<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### XOR (⊕):

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
<td>0</td>
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<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

### AND (∧):

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
<td>0</td>
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<td>1</td>
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<td>1</td>
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</tbody>
</table>

### NOT (¬):

<table>
<thead>
<tr>
<th>x</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
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Bit Operations on Words

Each of these bit operations can be applied to a word.

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.
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

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

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

**Unary:**
- \(\sim x\): Bitwise complement of \(x\) (0 → 1, 1 → 0)

**Binary:**
- \(x | y\): Bitwise OR of \(x\) and \(y\)
- \(x & y\): Bitwise AND of \(x\) and \(y\)
- \(x ^ y\): Bitwise XOR of \(x\) and \(y\)
- \(x << y\): Left shift \(x\) by \(y\) bits
- \(x >> y\): Right shift \(x\) by \(y\) bits
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*:

```c
#define LOWBIT 0x1

x = x | LOWBIT;
```

Later, we want to *unset bit zero*:

```c
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:

<table>
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\[ x = x ^ \text{LOWBIT}; \]
Shifting and Powers of 2

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

A one-bit shift is multiplying by 2:
- 0010 → 2
- 0100 → 4
- 0011 → 3
- 0110 → 6

**Successive bit shifts** continue to multiply by 2.
- 1 (= $2^0$)
- $1 << k$ (= $2^k$)
Forcing Endianness

```c
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

```c
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.
Required Readings


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