Bit Level Operators in C

C Programming and Software Tools

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"Bit Twiddling"

- C has operators that treat operands simply as sequences of bits
- Q: Why do bit level operations in C (or any language)?
- A#1: lets you pack information as efficiently as possible
- A#2: some processing is faster to implement with bit-level operations than with arithmetic operators

"Bit Twiddling"... (cont'd)

- Ex: image processing
  - pack 64 B&W pixel values into a single **`long long`** operand, and process 64 pixels with one instruction
  - mask one image with another to create overlays
- Other applications:
  - data compression,
  - encryption
  - error correction
  - I/O device control
  - ...

Working in Binary With C?

- There is no standard way to…
  - …write a constant in binary

```
i = 01011011;
```

  - …input an ASCII-encoded binary string and convert to an integer

```
scanf("%b", &i);
```

  - …output an integer as an ASCII-encoded binary string

```
printf("%b", i);
```

- Alternatives?
  - Use octal or hexadecimal representation

☠ common source of bugs ☠
thinking sequence of 1's and 0's means base 2

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BitOps: One Operand

- Bit-wise complement (~)
  - operand must be integer type
  - result is ones-complement of operand (flip every bit)
  - ex:

```
  ~0x0d   // (binary 00001101)
== 0xf2   // (binary 11110010)
```

Not the same as Logical NOT (!) or sign change (-)

```
char i, j1, j2, j3;
i = 0x0d;    // binary 00001101
j1 = ~i;     // binary 11110010
j2 = -i;     // binary 11110011
j3 = !i;     // binary 00000000
```


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BitOps: Two Operands

- Operate bit-by-bit on operands to produce a result operand of the same length
- And (&): result 1 if both inputs 1, 0 otherwise
- Or (|): result 1 if either input 1, 0 otherwise
- Xor (^): result 1 if one input 1, but not both, 0 otherwise
- Operands must be of type integer

Two Operands... (cont'd)

- Examples

```
00 111 000
&
11 011 110
----------
00 011 000
```

```
00 111 000
|
11 011 110
----------
11 111 110
```

```
00 111 000
^
11 011 110
----------
11 100 110
```

Differences: Logical and Bit Ops

Results?

```
int a, b, c,
    d, e, f;

int i = 30;
int j = 0;
a = i && j;
b = !j;
c = !i;

float x = 30.0;
float y = 0.0;
d = x || y;
e = !y;
f = !x;
```

common source of bugs
difference between logical and bit-level operators

Difference? Problems?

```
int a, b, c,
    d, e, f;

int i = 30;
int j = 0;
a = i & j;
b = ~j;
c = ~i;

float x = 30.0;
float y = 0.0;
d = x | y;
e = ~y;
f = ~x;
```


Shift Operations

- **x << y** is left (logical) shift of **x** by **y** positions
  - **x** and **y** must both be integers
  - **x** should be unsigned or positive
  - 0 <= **y** <= number of bits in **x**
  - **y** leftmost bits of **x** are discarded
  - zero fill **y** bits on the right

common source of bugs
logical shifts on negative numbers

these 3 bits are discarded

```
  01111001 << 3
--------------------
  11001000
```

these 3 bits are zero filled

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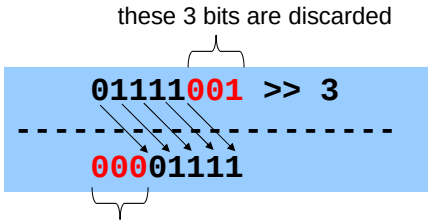
ShiftOps... (cont'd)

- **x >> y** is right (logical) shift of **x** by **y** positions
  - **y** rightmost bits of **x** are discarded
  - zero fill **y** bits on the left

☠ *common source of bugs* ☠
logical shifts on negative numbers



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ShiftOps... (cont'd)

- It is occasionally useful to know that...
  - right logical shift of an unsigned number x by y positions is equivalent to dividing x by 2^y
  - left logical shift of an unsigned number x by y positions is equivalent to multiplying x by 2^y

```
unsigned char j, k, m;
j = 121;
k = j << 3
m = j >> 3;
printf("%d %d %d\n", j, k, m);
```


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Other Useful Bit Operations

- Complementing, Anding, Oring, and Xoring bits are all provided directly by C operators
- What about the following?
  - clearing all or selected bits to 0's, or setting all or selected bits to 1's
  - testing if all or selected bits are 0's, or 1's
  - counting the number of bits that are 0's, or that are 1's
  - copying all or selected bits from x to y
  - copying a bit or bits from position i of x to position j of y

Clearing Bits to 0's

- Using C operators:
  - & with 0 will clear, & with 1 means "no change"
- So, create a mask with 0's where you want to clear, and 1's everywhere else

If input is...	And mask is...	Then input & mask =
0	0	0 (no change)
0	1	0 (no change)
1	0	0 (clear)
1	1	1 (no change)

Clearing... (cont'd)

- How would you clear (to **0**) all the bits in a **char**?

```
unsigned char m
= 0x00;
a = a & m;
```

```
a: 00 111 011
&
m: 00 000 000
-------------
a: 00 000 000
```

- How would you clear the right two bits (without changing the other bits)?

```
unsigned char m = 0374;
a = a & m;
```

```
a: 00 111 011
&
m: 11 111 100
-------------
a: 00 111 000
```


Setting Bits to 1's

- Using C operators:
  - | with 1 will set, | with 0 means "no change"
- So, create a mask with 1's where you want to set, and 0's everywhere else

If input is...	And mask is...	Then input | mask =
0	0	0 (no change)
0	1	1 (set)
1	0	1 (no change)
1	1	1 (no change)

Setting... (cont'd)

- How would you set (to **1**) all the bits in a **char** ?

```
unsigned char m = 0377;
a = a | m;
```

```
a: 00 111 110
|
m: 11 111 111
-------------

a: 11 111 111
```

- How would you set the right two bits without changing the other bits?

```
unsigned char m = 0003;
a = a | m;
```

```
a: 00 111 110
|
m: 00 000 011
-------------

a: 00 111 111
```


Complementing (Inverting) Bits

- Using C operators:
  - ^ with 1 will complement, ^ with 0 means "no change"
- So, create a mask with 1's where you want to complement, and 0's everywhere else

If input is...	And mask is...	Then input ^ mask =
0	0	0 (no change)
0	1	1 (complement)
1	0	1 (no change)
1	1	0 (complement)

Complementing... (cont'd)

- How would you complement (invert) all the bits in a **char** ?

```
unsigned char m = 0377;
a = a ^ m;

a = ~a; //also works
```

```
a: 00 111 110
^
m: 11 111 111
-------------
a: 11 000 001
```

- How would you complement the right two bits without changing the other bits?

```
unsigned char m = 0003;
a = a ^ m;
```

```
a: 00 111 110
^
m: 00 000 011
-------------
a: 00 111 101
```


Testing Bits for 1's

- Using C operators:
  1. & with 1 will where you want to test, & with 0 elsewhere
  2. then check if result == mask
- So, create a mask with 1's where you want to test, and 0's everywhere else

If input is...	And mask is...	Then input & mask =
0	0	0 (matches mask)
0	1	0 (won't match mask)
1	0	0 (matches mask)
1	1	1 (matches mask)

Test... (cont'd)

- How would you test (if == 1) all the bits in a **char** ?

```
unsigned char m = 0377;
if ((a & m) == m)
    ...
```

```
a: 00 111 110
&
m: 11 111 111
-------------
   00 111 110
```

- How would you test if the right two bits == 1?

```
unsigned char m = 0003;
if ((a & m) == m)
    ...
```

Not equal to m →

```
a: 00 111 110
&
m: 00 000 011
-------------
   00 000 010
```


Counting the Bits That Are 1's

- Using C operators:
  1. you already know how to test if a specific bit == 1
  2. do this for each bit, one at a time
  3. each time the bit == 1, add 1 to a counter
- A movable mask
  - (0001 << i) creates a mask with a 1 in the ith position from the right, and 0 everywhere else

Test... (cont'd)

- How would you count the number of bits == 1 in an unsigned char?

```
unsigned char m;
unsigned int cnt = 0;
for (i = 0; i < 8; i++) {
    m = 0001 << i;
    if ((a & m) == m)
        cnt += 1;
}
```


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Testing Bits for 0's

- Using C operators:
  - (you try it)
- How would you test (if == 0) all the bits in a char?

```
???
```

- How would you test if the two right bits == 0?

```
???
```


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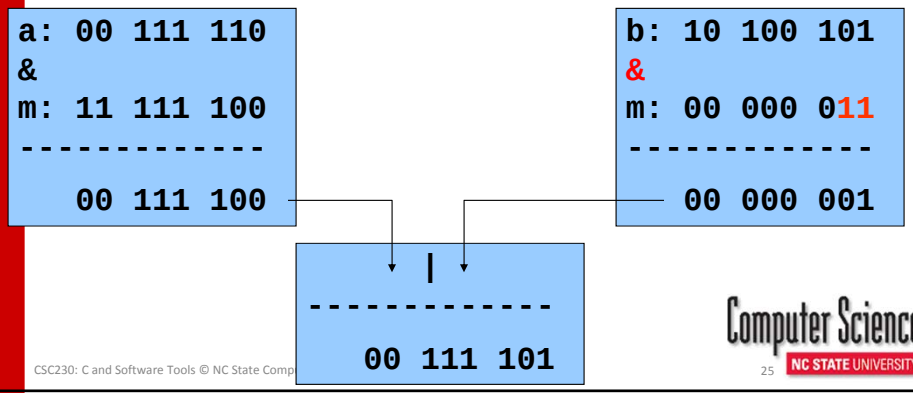
Copying Selected Bits (from b to a)

- Using C operators:
  - clear all the bits in a you do want to replace
  - clear all the bits in b you don't want to copy
  - | a with b to get result



★ you try it ★
bit operators

Exercise

1. Show the code to set the middle 4 bits of a to 1 (without changing the other bits)

2. What is the value (in binary) of b after executing:

```
b = 0354;
m = 0115;
b = b ^ m;
```

3. Show the code to copy the middle 4 bits of c to d (without changing the other bits); what is d (in binary) afterwards:

```
unsigned char c = 0326, d = 0154;
???
```