Bits and Bitwise Operators

Announcements

assign0 out, due Monday 4/9

  Focus is on getting comfortable in unix

  Note instructions for the readme

Piazza

  Great student contributions. Keep it up!

Office hours

  Regular schedule starts next week

Lab signups

SCPD students: expect an email soon with info

Roadmap

Next four weeks: various aspects of C

This week: data representation

How numbers are stored

Computer arithmetic

Limitations

Next week: pointers and memory

Goals for Today

Work with bits as individual units

Bitwise operators, masks

Use bits to represent C data types

Number bases (binary, hex)

Integer types

Characters

Use gdb to trace programs an inspect values

Definitions

bit (binary digit): a single 1 or 0

Can think of as true or false

byte: 8 bits

Smallest addressable unit

In C, there's no byte type

But char is always one byte

Bitwise Operators

`unsigned char a, b;`

a	0	0	1	1	0	1	0	1
b	0	1	0	1	0	0	1	1

Most significant bit (MSB)

Least significant bit (LSB)

Bitwise Operators

`unsigned char a, b;`

a	0	0	1	1	0	1	0	1
b	0	1	0	1	0	0	1	1

AND	a & b	0	0	0	1	0	0	0	1

Bitwise Operators

```
unsigned char a, b;
```

a		0	0	1	1	0	1	0	1
b		0	1	0	1	0	0	1	1

AND	a & b	0	0	0	1	0	0	0	1
OR	a | b	0	1	1	1	0	1	1	1

Bitwise Operators

`unsigned char a, b;`

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b	0	1	0	1	0	0	1	1

AND	a & b	0	0	0	1	0	0	0	1
OR	a | b	0	1	1	1	0	1	1	1
XOR	a ^ b	0	1	1	0	0	1	1	0

Bitwise Operators

```
unsigned char a, b;
```

	a	0	0	1	1	0	1	0	1
	b	0	1	0	1	0	0	1	1

AND	a & b	0	0	0	1	0	0	0	1
OR	a | b	0	1	1	1	0	1	1	1
XOR	a ^ b	0	1	1	0	0	1	1	0

NOT	~a	1	1	0	0	1	0	1	0

Bitwise Operators

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OR	a | b	0	1	1	1	0	1	1	1
XOR	a ^ b	0	1	1	0	0	1	1	0

NOT	~a	1	1	0	0	1	0	1	0
Left shift	a << 2	1	1	0	1	0	1		
Right shift	a >> 3				0	0	1	1	0

Bitwise Operators

`unsigned char a, b;`

a		0	0	1	1	0	1	0	1
b		0	1	0	1	0	0	1	1

AND	`a & b`	0	0	0	1	0	0	0	1
OR	`a | b`	0	1	1	1	0	1	1	1
XOR	`a ^ b`	0	1	1	0	0	1	1	0

NOT	`~a`	1	1	0	0	1	0	1	0
Left shift	`a << 2`	1	1	0	1	0	1	0	0
Right shift	`a >> 3`	0	0	0	0	0	1	1	0

Code Example: bits.c

So Far

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Binary Polynomial

Decimal: 5   0   7

10^2 10^1 10^0

$5 \cdot 10^2 + 0 \cdot 10^1 + 7 \cdot 10^0 = 507$

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Binary: 0   1   1   0   1   0   1   1

2^7 2^6 2^5 2^4 2^3 2^2 2^1 2^0

$0 \cdot 2^7 + 1 \cdot 2^6 + 1 \cdot 2^5 + 0 \cdot 2^4 + 1 \cdot 2^3 + 0 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0$

$64 + 32 + 8 + 2 + 1 = 107$

Number Bases

```
Decimal:    0     1     2     3     4     5     6     7
Binary:   0000  0001  0010  0011  0100  0101  0110  0111


Decimal:    8     9    10    11    12    13    14    15
Binary:   1000  1001  1010  1011  1100  1101  1110  1111


Decimal:   16    17
Binary:  10000 10001
```

Number Bases

```
Decimal:     0     1     2     3     4     5     6     7
Binary:   0000  0001  0010  0011  0100  0101  0110  0111
Hex:         0     1     2     3     4     5     6     7

Decimal:     8     9    10    11    12    13    14    15
Binary:   1000  1001  1010  1011  1100  1101  1110  1111
Hex:         8     9     a     b     c     d     e     f

Decimal:    16    17
Binary:  10000 10001
Hex:        10    11
```

Hexadecimal (base 16)

  Compact, easy conversion to/from binary

  Use in C code with 0x prefix

Conversion

```
Decimal:     0     1     2     3     4     5     6     7
Binary:   0000  0001  0010  0011  0100  0101  0110  0111
Hex:         0     1     2     3     4     5     6     7

Decimal:     8     9    10    11    12    13    14    15
Binary:   1000  1001  1010  1011  1100  1101  1110  1111
Hex:         8     9     a     b     c     d     e     f
```

Binary	Hex	Polynomial	Decimal
0101 1100			

Conversion

```
Decimal:      0    1     2     3     4     5     6     7
Binary:    0000 0001  0010  0011  0100  0101  0110  0111
Hex:          0    1     2     3     4     5     6     7

Decimal:      8    9    10    11    12    13    14    15
Binary:    1000 1001  1010  1011  1100  1101  1110  1111
Hex:          8    9     a     b     c     d     e     f
```

Binary	Hex	Polynomial	Decimal
0101 1100	0x5c		

Conversion

```
Decimal:     0    1    2    3    4    5    6    7
Binary:   0000 0001 0010 0011 0100 0101 0110 0111
Hex:         0    1    2    3    4    5    6    7

Decimal:     8    9   10   11   12   13   14   15
Binary:   1000 1001 1010 1011 1100 1101 1110 1111
Hex:         8    9    a    b    c    d    e    f
```

Binary	Hex	Polynomial	Decimal
0101 1100	0x5c	64 + 16 + 8 + 4	92

Conversion

```
Decimal:     0    1    2    3    4    5    6    7
Binary:   0000 0001 0010 0011 0100 0101 0110 0111
Hex:         0    1    2    3    4    5    6    7

Decimal:     8    9   10   11   12   13   14   15
Binary:   1000 1001 1010 1011 1100 1101 1110 1111
Hex:         8    9    a    b    c    d    e    f
```

Binary	Hex	Polynomial	Decimal
0101 1100	0x5c	64 + 16 + 8 + 4	92
		128 + 16 + 4 + 2	150

Conversion

```
Decimal:     0     1     2     3     4     5     6     7
Binary:   0000  0001  0010  0011  0100  0101  0110  0111
Hex:         0     1     2     3     4     5     6     7

Decimal:     8     9    10    11    12    13    14    15
Binary:   1000  1001  1010  1011  1100  1101  1110  1111
Hex:         8     9     a     b     c     d     e     f
```

Binary	Hex	Polynomial	Decimal
0101 1100	0x5c	64 + 16 + 8 + 4	92
1001 0110	0x96	128 + 16 + 4 + 2	150

Note: Same number, different representation

Range and Data Types

1 byte = 8 bits = 2 hex digits

`0xff` = 1111 1111 (bin) = 255

C integer data types (unsigned)

`char`: 1 byte, 0 to 255

`short`: 2 bytes, 0 to ~65,000

`int`: 4 bytes, 0 to ~4 billion

`long`: 8 bytes, 0 to [big number]

ASCII: Representing Characters

Dec	Hex	Char	Dec	Hex	Char
0	0x0	'\0'	65	0x41	'A'
			66	0x42	'B'
	...			...	
32	0x20	' '	90	0x5a	'Z'
33	0x21	'!'			
	...			...	
48	0x30	'0'	97	0x61	'a'
49	0x31	'1'	98	0x62	'b'
	...			...	
57	0x39	'9'	122	0x7a	'z'
	...			...	

Summary

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Next time: arithmetic and signed integers