Using Different Bases in Code

How do we define numbers in our code (C, Java, Python, ...)?

	Old Languages (C, Java?)	New Languages (Python, ...)
binary	No!	0b110101010
octal	02130	0o2130 ~~[illegible]~~ 0o72
decimal	2130	2130
hexadecimal	0x86	0x86

m

Bitwise Operations

CS 2130: Computer Systems and Organization 1

September 5, 2025

Announcements

- Quiz 1 opens this afternoon, due Sunday night
- Homework 1 due September 15
- SDAC is looking for a volunteer notetaker for our section
  - Please consider signing up and adding your notes
  - More details coming in the weekly email today

Representing Negative Integers

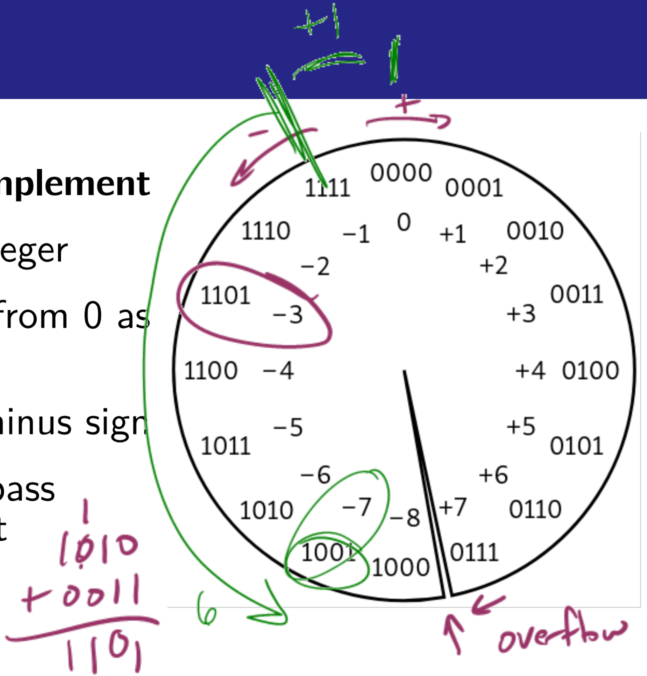
Computers store numbers in fixed number of wires

- Ex: consider 4-digit decimal numbers
- Throw away the last borrow:
  - 0000 - 0001 = 9999 == -1
  - 9999 - 0001 = 9998 == -2
  - Normal subtraction/addition still works
  - Ex: -2 + 3
- This works the same in binary

Two's Complement

This scheme is called **Two's Complement**

- More generically, a *signed* integer
- There is a break as far away from 0 as possible
- First bit acts vaguely like a minus sign
- Works as long as we do not pass number too large to represent



Two's Complement

Values of Two's Complement Numbers

Consider the following 8-bit binary number in Two's Complement:

$$11010011 \leftarrow -45$$

What is its value in decimal?

```
  1 1 1 1 1 1 1 1   <- carry bits
    1 1 0 1 0 0 1 1
+   0 0 1 0 1 1 0 1
-------------------
    0 0 0 0 0 0 0 0
```

```
   11111111   (-1)
 - 11010011
 ----------
   00101100
 +        1
 ----------
   00101101  = 45
```

Values of Two's Complement Numbers

Consider the following 8-bit binary number in Two's Complement:

$$11010011$$

What is its value in decimal?

1. Flip all bits ~
2. Add 1

Addition

```
   1111        ← carry
   01001010  = 74
+  01111100  = 124
-----------
   11000110  = ~~198~~ ?  -58

   00111001
+         1
-----------
   00111010  = 58
```

Subtraction

```
    01001010   = 74
  - 01111100   = 124
  ----------
    11001110   = -50
```

0111... − 1 = 127 (borrow) ... −128

```
~ 00110001  ← 49
+1       1  ← 1
  --------
  00110010  ← 50
```

14 − 18

Operations

So far, we have discussed:

- Addition: $x + y$
  - Can get multiplication
- Subtraction: $x - y$
  - Can get division, but more difficult
- Unary minus (negative): $-x$
  - Flip the bits and add 1

Operations (on Integers)

Bit vector: fixed-length sequence of bits (ex: bits in an integer)

- Manipulated by bitwise operations

Bitwise operations: operate over the bits in a bit vector

- Bitwise not: `~x` - flips all bits (unary)
- Bitwise and: `x & y` - set bit to 1 if x, y have 1 in same bit
- Bitwise or: `x | y` - set bit to 1 if either x or y have 1
- Bitwise xor: `x ^ y` - set bit to 1 if x, y bit differs

Example: Bitwise AND

```
  11001010
& 01111100
----------
  01001000
```

Example: Bitwise OR

```
   11001010
|  01111100
-----------
   11111110
```

Example: Bitwise XOR

```
   11001010
^  01111100
-----------
   10110110
```

Your Turn!

What is: `0x1a ^ 0x72`

0x1a = 0001 1010 (1, a)

0x72 = 0111 0010 (7, 2)

0110 1000 = 0x68 (6, 8)

Operations (on Integers)

- Logical not: $!x$
  - $!0 = 1$ and $!x = 0, \forall x \neq 0$
  - Useful in C, no booleans
  - Some languages name this one differently

Operations (on Integers)

- Left shift: $x << y$ - move bits to the left
  - Effectively multiply by powers of 2
- Right shift: $x >> y$ - move bits to the right
  - Effectively divide by powers of 2
  - Signed (extend sign bit) vs unsigned (extend 0)

Left Bit-shift Example

`01011010 << 2`

Right Bit-shift Example

```
01011010 >> 3
```

Bit-shift

Computing bit-shift effectively multiplies/divides by powers of 2

Consider decimal:

$$2130 \ll_{10} 2 = 213000 = 2130 \times 100$$

$$2130 \gg_{10} 1 = 213 = 2130 \,/\, 10$$

Right Bit-shift Example 2

```
11001010 >> 1
```

Right Bit-shift Example 2

For **signed** integers, extend the sign bit (1)

- Keeps negative value (if applicable)
- Approximates divide by powers of 2

```
11001010 >> 1
```

Bit fiddling example