

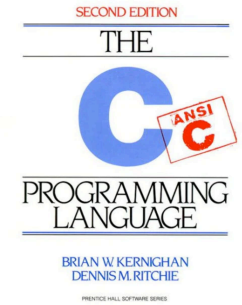
# CSC 411

## Computer Organization (Spring 2024) Lecture 4: Integers (signed, unsigned)

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## The C Language

- Developed by Dennis Ritchie at Bell Labs in the early 1970s
- Many operating systems, including Unix and its variants (Linux), are written in C
- Allows low-level access to memory, making it efficient for system programming
- C programs are generally portable across different platforms with minimal modification
- C follows a traditional compilation process, where the source code is translated into machine code by a compiler



## TIOBE Index for January 2024

- Indicator of the popularity of programming languages
  - popular search engines such as Google, Bing, Yahoo!, Wikipedia, Amazon, YouTube and Baidu are used to calculate the ratings.

Jan 2024	Jan 2023	Change	Programming Language	Ratings	Change
1	1		 Python	13.97%	-2.39%
2	2		 C	11.44%	-4.81%
3	3		 C++	9.96%	-2.95%
4	4		 Java	7.87%	-4.34%
5	5		 C#	7.16%	+1.43%
6	7	▲	 JavaScript	2.77%	-0.11%
7	10	▲	 PHP	1.79%	+0.40%
8	6	▼	 Visual Basic	1.60%	-3.04%
9	8	▼	 SQL	1.46%	-1.04%
10	20	▲	 Scratch	1.44%	+0.86%

<https://www.tiobe.com/tiobe-index/>

## Representing data

## Representing data

- In memory, **all values** are stored as “bit-vectors”
  - **data types** are used to interpret the bits (provide meaning)
  - each possible bit-vector assigned exclusively to one meaning
- In a bit sequence of  $w$  bits, we can represent  $2^w$  different values
  - number of permutations with repetition — given  $w$  digits, there are two ways to choose each digit
  - example: how many different sequences can be represented in 4 bits?

0 0 0 0	1 0 0 0
0 0 0 1	1 0 0 1
0 0 1 0	1 0 1 0
0 0 1 1	1 0 1 1
0 1 0 0	1 1 0 0
0 1 0 1	1 1 0 1
0 1 1 0	1 1 1 0
0 1 1 1	1 1 1 1

$$2^4 = 16$$

## What is this program doing?

```
#include <stdio.h>

int main() {
    unsigned hex = 0x7e313134;

    float *f = (float *) &hex;
    char *s = (char *) &hex;

    printf("%u %d %.4ef %c%c%c%c",
           hex, hex, *f, s[0], s[1], s[2], s[3]);

    return 0;
}
```

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## Interlude: addition and multiplication

### Binary addition

	1	1	1					
	0	0	1	1	1	0	0	1
+	0	1	1	1	0	1	1	0
	1	0	1	0	1	1	1	1

	1				1	1	1	
	1	1	0	0	0	1	1	1
+	0	1	0	1	0	1	1	1
	1	0	0	0	1	1	1	0

## Binary multiplication

				1	0	0	1		
				0	1	1	0		
				0	0	0	0		
			1	0	0	1			
		1	0	0	1				
	0	0	0	0					
0	1	1	0	1	1	0			

				1	1	1	1		
				1	1	1	1		
				1	1	1	1		
			1	1	1	1			
		1	1	1	1				
	1	1	1	0	0	0	0	1	

Tricky? perform the addition row-by-row

## Integer Representation (unsigned, signed)

## Unsigned integers

- Bits represent the number directly
  - same as binary-to-decimal conversion
  - $w$  bits can represent  $2^w$  unsigned integers ranging from 0 to  $2^w - 1$

0 0 0 0 = 0	1 0 0 0 = 8
0 0 0 1 = 1	1 0 0 1 = 9
0 0 1 0 = 2	1 0 1 0 = 10
0 0 1 1 = 3	1 0 1 1 = 11
0 1 0 0 = 4	1 1 0 0 = 12
0 1 0 1 = 5	1 1 0 1 = 13
0 1 1 0 = 6	1 1 1 0 = 14
0 1 1 1 = 7	1 1 1 1 = 15

## Overflow

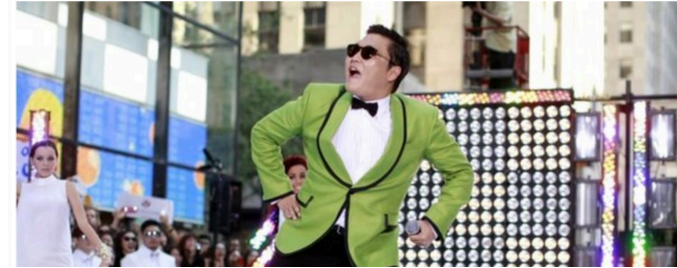
- Assume  $w = 8$  is the bit-width
  - what happens if you try to add 1 to 11111111? => **Overflow**
  - there's no room for a number larger than 255 !
- The arithmetic "wraps around" back to the beginning of the range
  - adding 1 to 255 in an 8-bit system results in 0 (leading bit is discarded)
  - this wrapping around behavior can be useful in certain situations
  - applies to unsigned integers
    - basically taking the result  $\bmod 2^w$  or taking the lowest  $w$  bits

# Overflow

- Occurs when the result of an operation is **too large or too small** to be represented within the allocated data type
  - in C, the runtime does not produce errors, values just “**wrap**”
- Can have consequences if not handled properly
  - incorrect calculations
  - program crashes due to unexpected behavior
  - security vulnerabilities
- To prevent overflow
  - choose appropriate data types with sufficient range
  - implement checks and validations within the code

## Gangnam Style music video 'broke' YouTube view limit

4 December 2014



YouTube said the video - its most watched ever - has been viewed more than **2,147,483,647** times. It has now changed the maximum view limit to **9,223,372,036,854,775,808**, or more than nine quintillion.

## Zero-Day Alert: Google Chrome Under Active Attack, Exploiting New Vulnerability

Nov 29, 2023 Newsroom



Google has rolled out security updates to fix seven security issues in its Chrome browser, including a zero-day that has come under active exploitation in the wild.

Tracked as CVE-2023-6345, the high-severity vulnerability has been described as an integer overflow bug in Skia, an open source 2D graphics library.

A zero-day attack takes place when hackers exploit the flaw before developers have a chance to address it.

## Signed integers

- Trivial approach (not used)
  - use MSB as the sign bit, and the remaining bits to represent the number
  - all possibilities using  $w = 3$  bits:

0 0 0 = 0  
0 0 1 = 1  
0 1 0 = 2  
0 1 1 = 3  
1 0 0 = -0  
1 0 1 = -1  
1 1 0 = -2  
1 1 1 = -3

how is zero represented?  
would addition still work?  
(try adding 001 and 110)

## Going from $x$ to $-x$ (and vice-versa)

### ▸ One's complement of $x$ :

- flip all bits in  $x$
- called complement because  $x + -x = 11\dots11$

### ▸ Two's complement of $x$

- flip all bits in  $x$  and add 1 to the result
- $\sim x + 1$  (apply bitwise)

## Using $w = 4$ bits

Binary	Unsigned	One's complement	Two's complement
0000	0	+0	0
0001	1	1	1
0010	2	2	2
0011	3	3	3
0100	4	4	4
0101	5	5	5
0110	6	6	6
0111	7	7	7
1000	8	-7	-8
1001	9	-6	-7
1010	10	-5	-6
1011	11	-4	-5
1100	12	-3	-4
1101	13	-2	-3
1110	14	-1	-2
1111	15	-0	-1

## Practice

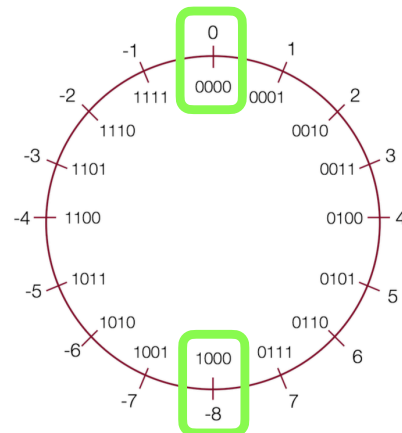
### ▸ Convert from $x$ to $-x$ using two's complement

0 0 1 1 =

1 1 1 1 =

1 0 0 0 =

1 1 0 1 =



## The most negative number

### ▸ Exceptions to $\sim x + 1$

- zero becomes zero (overflow)
- the most negative number does not have a positive counterpart — impossible to represent (overflow)

### ▸ Can lead to unexpected programming bugs

- the unary negation operator,  $-(-128)$  becomes -128
- the absolute value may return a negative number,  $\text{abs}(-128)$  becomes -128
- multiplication by -1 may fail,  $-128 * -1$  becomes -128
- division by -1 may cause an exception,  $-128 / -1$  crashes

### ▸ In C the above behaviors are undefined

## From two's complement to decimal

$$\sum_{i=0}^{w-1} x_i 2^i - x_{w-1} 2^{w-1} + \sum_{i=0}^{w-2} x_i 2^i$$

Conversion to decimal for unsigned representations

Conversion to decimal for two's complement representations

Although C does not mandate using two's complement, in practice, two's complement is the **most widely used** representation for signed integers in modern computer systems.

## Practice

- Convert from two's complement to decimal

-32 16 8 4 2 1  
0 0 1 1 1 0 =  
1 1 0 0 0 1 =  
1 0 0 0 0 0 =  
1 1 1 1 1 1 =  
1 1 1 1 1 0 =  
0 0 0 0 0 0 =  
0 0 0 0 0 1 =  
0 1 1 1 1 1 =

## Two's complement (summary)

- Sign bit (MSB)
  - 0 for nonnegative, 1 for negative
- Non-negative numbers
  - no changes from the unsigned representation
- Negative numbers
  - two's complement of their positive counterparts
    - equivalent to their one's complement plus one

Binary	Unsigned	Signed (two's complement)
01010101	85	85
10101011	171	-85

## Two's complement (advantages)

- Addition and subtraction of signed integers
  - use the same hardware as their unsigned counterparts
  - no need for special/additional circuitry
- Single representation for zero
  - no negative zero
- Trivial operation for extending the sign bit
  - e.g. increasing the bit-width of a number (**casting**)
- Widespread adoption

## Numeric ranges

### ▸ Unsigned representation

- min  $\Rightarrow$  00...00      0
- max  $\Rightarrow$  11...11       $2^w - 1$

### ▸ Signed representation (two's complement)

- min  $\Rightarrow$  10...00       $-2^{w-1}$
- max  $\Rightarrow$  01...11       $2^{w-1} - 1$

data type	binary	hexadecimal	decimal
unsigned short int (min)			
unsigned short int (max)			
short int (min)			
short int (max)			

## Basic data types in C

### ▸ The C standard does not define the size of “integer” types, except **char**

- much safer to use **intN\_t** and **uintN\_t** for signed and unsigned integers of different sizes (**stdint.h**)

### ▸ The type of each variable tells the compiler how many bytes are necessary in memory

- necessary for translation of high level code into machine code

```
#include <stdint.h>

int main() {
    // unsigned integer using 4 bytes ==> 0x000000C8
    // 0000 0000 0000 0000 0000 0000 1100 1000
    uint32_t myvar = 200;
    // ....
    return 0;
}
```

## Range of values

Data type	Size	Format	Value range
character	8	signed	-128 to 127
		unsigned	0 to 255
integer	16	signed	-32768 to 32767
		unsigned	0 to 65535
	32	signed	-2,147,483,648 to 2,147,483,647
		unsigned	0 to 4,294,967,295
	64	signed	-9,223,372,036,854,775,808 to 9,223,372,036,854,775,807
		unsigned	0 to 18,446,744,073,709,551,615