

COMP201

Computer Systems & Programming

Lecture #02 – A Tour of C Programs, Bits & Bytes



KOÇ
UNIVERSITY

Aykut Erdem // Koç University // Fall 2020

Plan For Today

- Getting Started With C
- Bits and Bytes
- Hexadecimal
- Integer Representations
- Unsigned Integers

Disclaimer: Slides for this lecture were borrowed from
—Nick Troccoli's Stanford CS107 class

Good news, everyone!

- Lab preference submissions are open! You may submit your preferences anytime until ~~Friday 10/9 at 5PM~~ Thursday 10/9 at 11:59PM.
- Assg0 will be out today (due Oct 16)
- C bootcamp (today & tomorrow)



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The C Language

C was created around 1970 to make writing Unix and Unix tools easier.

- Part of the C/C++/Java family of languages (C++ and Java were created later)
- Design principles:
 - Small, simple abstractions of hardware
 - Minimalist aesthetic
 - Prioritizes efficiency and minimalism over safety and high-level abstractions

C vs. C++ and Java

They all share:

- Syntax
- Basic data types
- Arithmetic, relational, and logical operators

C doesn't have:

- More advanced features like operator overloading, default arguments, pass by reference, classes and objects, ADTs, etc.
- Extensive libraries (no graphics, networking, etc.) – this means not much to learn C!
- many compiler and runtime checks (this may cause security vulnerabilities!)

Programming Language Philosophies

- **C is procedural:** you write functions, rather than define new variable types with classes and call methods on objects. C is small, fast and efficient.
- **C++ is procedural, with objects:** you write functions, and define new variable types with classes, and call methods on objects.
- **Python is also procedural, but dynamically typed:** you still write functions and call methods on objects, but the development process is very different.
- **Java is object-oriented:** virtually everything is an object, and everything you write needs to conform to the object-oriented design pattern.

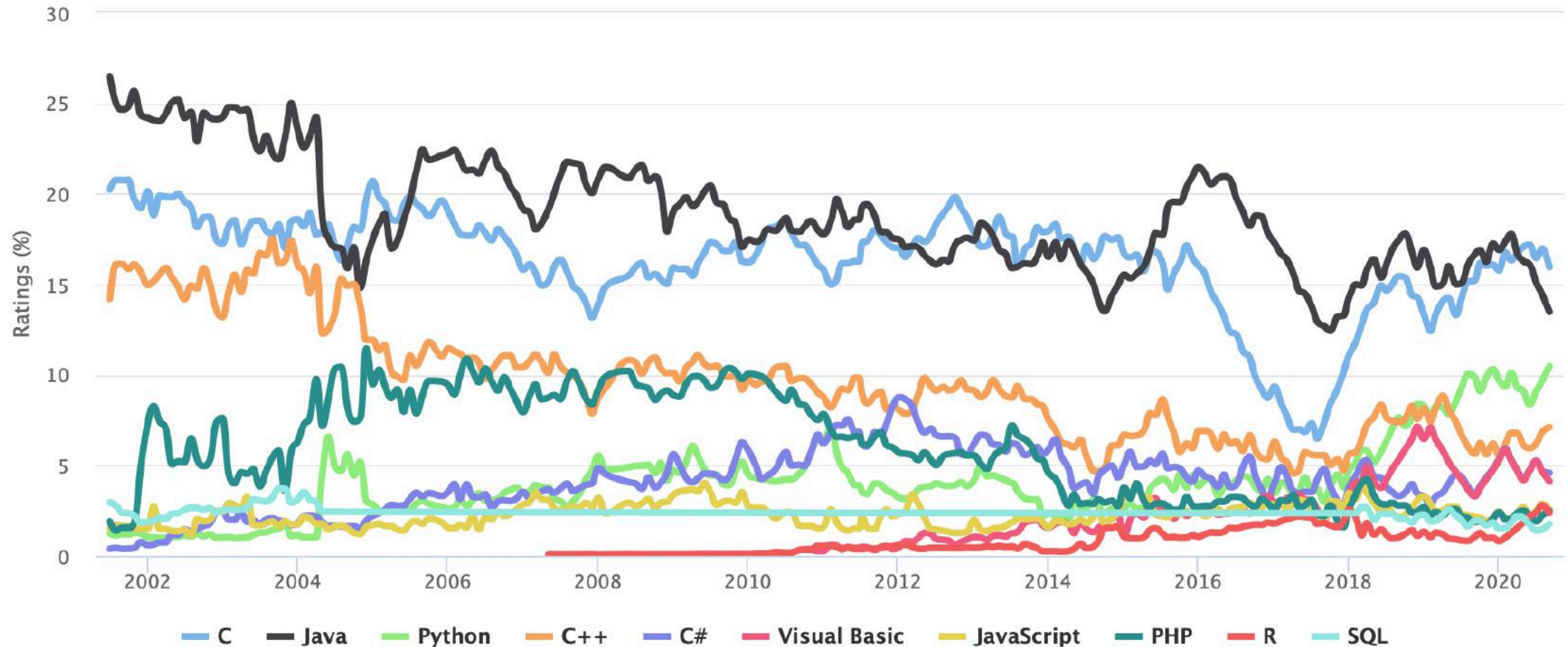
Why C?

- Many tools (and even other languages, like Python!) are built with C.
- C is the language of choice for fast, highly efficient programs.
- C is popular for systems programming (operating systems, networking, etc.)
- C lets you work at a lower level to manipulate and understand the underlying system.

Programming Language Popularity

TIOBE Programming Community Index

Source: www.tiobe.com



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

Our First C Program

```
/*  
 * hello.c  
 * This program prints a welcome message  
 * to the user.  
 */  
#include <stdio.h>    // for printf  
  
int main(int argc, char *argv[]) {  
    printf("Hello, world!\n");  
    return 0;  
}
```

Our First C Program

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Program comments

You can write block or inline comments.

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}
```

Import statements

C libraries are written with angle brackets.
Local libraries have quotes:

```
#include "lib.h"
```

Our First C Program

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 */  
#include <stdio.h>    // for printf
```

```
int main(int argc, char *argv[]) {  
    printf("Hello, world!\n");  
    return 0;  
}
```

main function – entry point for the program
Should always return an integer (0 = success)

Our First C Program

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#include <stdio.h>    // for printf

int main(int argc, char *argv[]) {
    printf("Hello, world!\n");
    return 0;
}
```

Main parameters – main takes two parameters, both relating to the command line arguments used to execute the program.

argc is the number of arguments in **argv**
argv is an array of arguments (**char *** is C string)

Our First C Program

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}
```

printf – prints output to the screen

Familiar Syntax

```
int x = 42 + 7 * -5;           // variables, types
double pi = 3.14159;
char c = 'Q';                  /* two comment styles */

for (int i = 0; i < 10; i++) {  // for loops
    if (i % 2 == 0) {           // if statements
        x += i;
    }
}

while (x > 0 && c == 'Q' || b) { // while loops, logic
    x = x / 2;
    if (x == 42) { return 0; }
}

binky(x, 17, c);               // function call
```

Boolean Variables

To declare Booleans, (e.g. **bool b = _____**), you must include **stdbool.h**:

```
#include <stdio.h>    // for printf
#include <stdbool.h>   // for bool

int main(int argc, char *argv[]) {
    bool x = 5 > 2 && binky(argc) > 0;
    if (x) {
        printf("Hello, world!\n");
    } else {
        printf("Howdy, world!\n");
    }
    return 0;
}
```

Boolean Expressions

C treats a nonzero value as true, and a zero value as false:

```
#include <stdio.h>

int main(int argc, char *argv[]) {
    int x = 5;
    if (x) {    // true
        printf("Hello, world!\n");
    } else {
        printf("Howdy, world!\n");
    }
    return 0;
}
```

Console Output: printf

```
printf(text, arg1, arg2, arg3);
```

```
// Example
```

```
char *classPrefix = "COMP";
```

```
int classNumber = 201;
```

```
printf("You are in %s%d", classPrefix, classNumber);    // You are in COMP201
```

`printf` makes it easy to print out the values of variables or expressions.

If you include *placeholders* in your printed text, `printf` will replace each placeholder *in order* with the values of the parameters passed after the text.

`%s` (string)

`%d` (integer)

`%f` (double)

Question Break!

Writing, Debugging and Compiling

We will use:

- the **vi/emacs** text editor to write our C programs
- the **make** tool to compile our C programs
- the **gdb** debugger to debug our programs
- the **valgrind** tools to debug memory errors and measure program efficiency

Demo: Compiling And Running A C Program



Working On C Programs Recap

- **ssh** – remotely log in to `linuxpool` computers (*later*)
- **Vi/Emacs** – text editor to write and edit C programs
 - Use the mouse to position cursor, scroll, and highlight text
 - `:w` / `Ctl-x Ctl-s` to save, `:q` / `Ctl-x Ctl-c` to quit
- **make** – compile program using provided Makefile
- `./myprogram` – run executable program (optionally with arguments)
- **make clean** – remove executables and other compiler files
- Lecture codes are accessible at Blackboard

COMP201 Topic 1: How can a computer represent integer numbers?

Demo: Unexpected Behavior



airline.c

Plan For Today

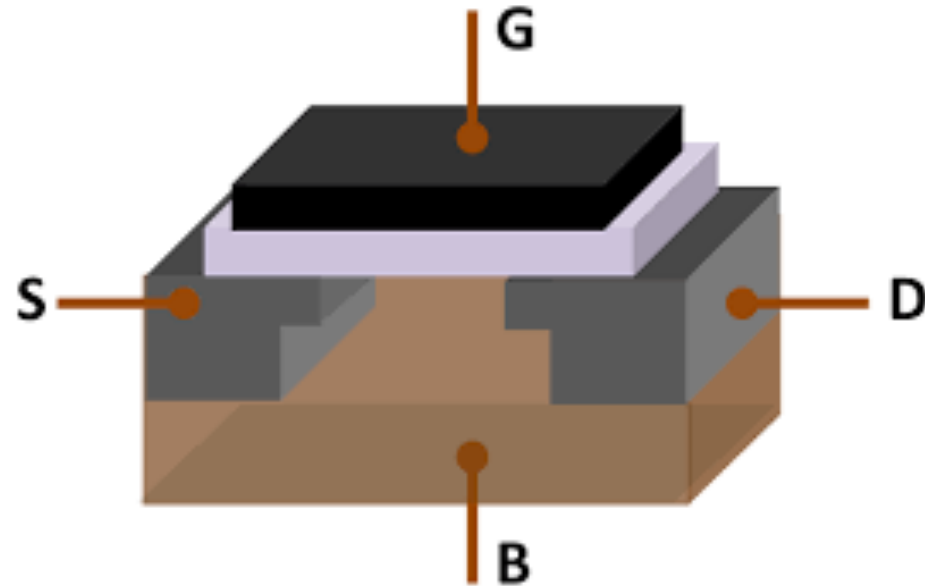
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0

1

Bits

- Computers are built around the idea of two states: “on” and “off”. Transistors represent this in hardware, and bits represent this in software!



One Bit At A Time

- We can combine bits, like with base-10 numbers, to represent more data. **8 bits = 1 byte.**
- Computer memory is just a large array of bytes! It is *byte-addressable*; you can't address (store location of) a bit; only a byte.
- Computers still fundamentally operate on bits; we have just gotten more creative about how to represent different data as bits!
 - Images
 - Audio
 - Video
 - Text
 - And more...

Base 10

5 9 3 4

Digits 0-9 (0 to base-1)

Base 10

5 9 3 4

↑ ↑ ↑ ↑

thousands hundreds tens ones

$$= 5*1000 + 9*100 + 3*10 + 4*1$$

Base 10

5 9 3 4

↑ ↑ ↑ ↑

10^3 10^2 10^1 10^0

Base 10

	5	9	3	4
10^x :	3	2	1	0

Base 2

	1	0	1	1
2^x :	3	2	1	0

Digits 0-1 (*0* to *base-1*)

Base 2

1 0 1 1

2^3 2^2 2^1 2^0

Base 2

Most significant bit (MSB)

Least significant bit (LSB)

1 0 1 1
eights fours twos ones

$$= 1*8 + 0*4 + 1*2 + 1*1 = 11_{10}$$

Base 10 to Base 2

Question: What is 6 in base 2?

- Strategy:
 - What is the largest power of $2 \leq 6$?

Base 10 to Base 2

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- Strategy:
 - What is the largest power of $2 \leq 6$? $2^2=4$

0	1		
<hr/>	<hr/>	<hr/>	<hr/>
2^3	2^2	2^1	2^0

Base 10 to Base 2

Question: What is 6 in base 2?

- Strategy:
 - What is the largest power of $2 \leq 6$? $2^2=4$
 - Now, what is the largest power of $2 \leq 6 - 2^2$?

0	1		
<hr/>	<hr/>	<hr/>	<hr/>
2^3	2^2	2^1	2^0

Base 10 to Base 2

Question: What is 6 in base 2?

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- What is the largest power of $2 \leq 6$? $2^2=4$
- Now, what is the largest power of $2 \leq 6 - 2^2$? $2^1=2$

$$\begin{array}{cccc} 0 & 1 & 1 & \\ \hline 2^3 & 2^2 & 2^1 & 2^0 \end{array}$$

Base 10 to Base 2

Question: What is 6 in base 2?

- Strategy:
 - What is the largest power of $2 \leq 6$? $2^2=4$
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 - $6 - 2^2 - 2^1 = 0$!

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Base 10 to Base 2

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$$\begin{array}{cccc} 0 & 1 & 1 & 0 \\ \hline 2^3 & 2^2 & 2^1 & 2^0 \\ \hline \end{array} \\ = 0*8 + 1*4 + 1*2 + 0*1 = 6$$

Practice: Base 2 to Base 10

What is the base-2 value 1010 in base-10?

- a) 20
- b) 101
- c) 10
- d) 5
- e) Other

Practice: Base 10 to Base 2

What is the base-10 value 14 in base 2?

- a) 1111
- b) 1110
- c) 1010
- d) Other

Byte Values

- What is the minimum and maximum base-10 value a single byte (8 bits) can store?

Byte Values

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Byte Values

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

Byte Values

- What is the minimum and maximum base-10 value a single byte (8 bits) can store? minimum = 0 maximum = ?

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

- Strategy 1:** $1 \cdot 2^7 + 1 \cdot 2^6 + 1 \cdot 2^5 + 1 \cdot 2^4 + 1 \cdot 2^3 + 1 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0 = 255$

Byte Values

- What is the minimum and maximum base-10 value a single byte (8 bits) can store? minimum = 0 maximum = 255

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

- Strategy 1: $1*2^7 + 1*2^6 + 1*2^5 + 1*2^4 + 1*2^3 + 1*2^2 + 1*2^1 + 1*2^0 = 255$
- Strategy 2: $2^8 - 1 = 255$

Multiplying by Base

$$1450 \times 10 = 1450\underline{0}$$

$$1100_2 \times 2 = 1100\underline{0}$$

Key Idea: inserting 0 at the end multiplies by the base!

Dividing by Base

$$1450 / 10 = 145$$

$$1100_2 / 2 = 110$$

Key Idea: removing 0 at the end divides by the base!


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Hexadecimal

- When working with bits, oftentimes we have large numbers with 32 or 64 bits.
- Instead, we'll represent bits in *base-16 instead*; this is called hexadecimal.

0110 1010 0011



0-15 0-15 0-15

Hexadecimal

- When working with bits, oftentimes we have large numbers with 32 or 64 bits.
- Instead, we'll represent bits in *base-16 instead*; this is called hexadecimal.



Each is a base-16 digit!

Hexadecimal

- Hexadecimal is *base-16*, so we need digits for 1-15. How do we do this?

0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
										10	11	12	13	14	15

Hexadecimal

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

Hex digit	8	9	A	B	C	D	E	F
Decimal value	8	9	10	11	12	13	14	15
Binary value	1000	1001	1010	1011	1100	1101	1110	1111

Hexadecimal

- We distinguish hexadecimal numbers by prefixing them with **0x**, and binary numbers with **0b**.
- E.g. **0xf5** is **0b11110101**

0x f 5

1111 0101

Practice: Hexadecimal to Binary

What is **0x173A** in binary?

Hexadecimal	1	7	3	A
Binary	0001	0111	0011	1010

Practice: Hexadecimal to Binary

What is **0b1111001010** in hexadecimal? (*Hint: start from the right*)

Binary	11	1100	1010
Hexadecimal	3	C	A

Question Break!

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Number Representations

- **Unsigned Integers:** positive and 0 integers. (e.g. 0, 1, 2, ... 99999...)
- **Signed Integers:** negative, positive and 0 integers. (e.g. ...-2, -1, 0, 1,... 9999...)
- **Floating Point Numbers:** real numbers. (e,g. 0.1, -12.2, 1.5×10^{12})

Number Representations

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 More on this next week!

Number Representations

C Declaration	Size (Bytes)
int	4
double	8
float	4
char	1
char *	8
short	2
long	8

In The Days Of Yore...

C Declaration	Size (Bytes)
int	4
double	8
float	4
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char *	4
short	2
long	4

Transitioning To Larger Datatypes



- **Early 2000s:** most computers were **32-bit**. This means that pointers were **4 bytes (32 bits)**.
- 32-bit pointers store a memory address from 0 to $2^{32}-1$, equaling **2^{32} bytes of addressable memory**. This equals **4 Gigabytes**, meaning that 32-bit computers could have at most **4GB** of memory (RAM)!
- Because of this, computers transitioned to **64-bit**. This means that datatypes were enlarged; pointers in programs were now **64 bits**.
- 64-bit pointers store a memory address from 0 to $2^{64}-1$, equaling **2^{64} bytes of addressable memory**. This equals **16 Exabytes**, meaning that 64-bit computers could have at most **$1024*1024*1024$ GB** of memory (RAM)!

Lecture Plan

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Unsigned Integers

- An **unsigned** integer is 0 or a positive integer (no negatives).
- We have already discussed converting between decimal and binary, which is a nice 1:1 relationship. Examples:

$$0b0001 = 1$$

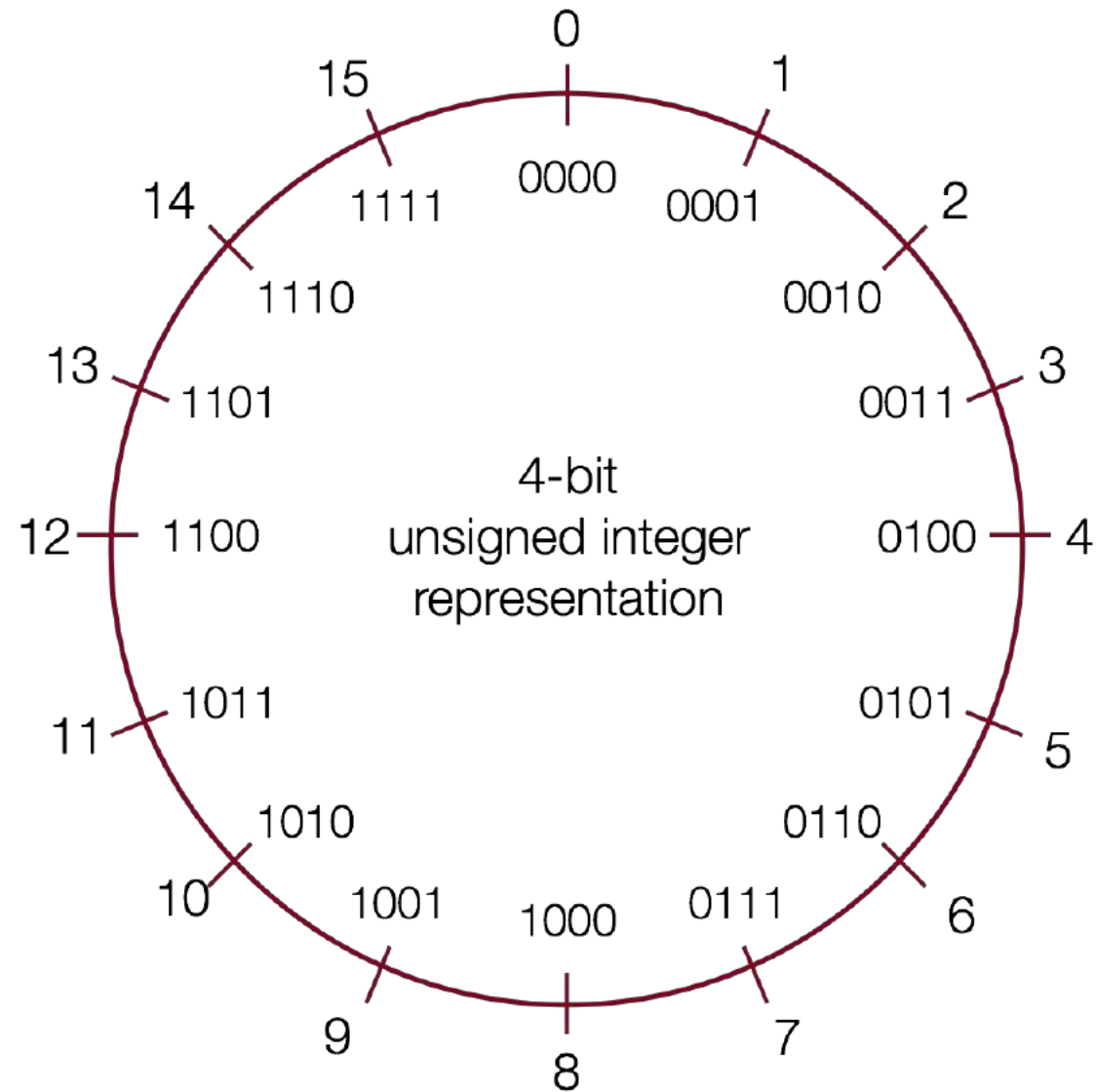
$$0b0101 = 5$$

$$0b1011 = 11$$

$$0b1111 = 15$$

- The range of an unsigned number is $0 \rightarrow 2^w - 1$, where w is the number of bits. E.g. a 32-bit integer can represent 0 to $2^{32} - 1$ (4,294,967,295).

Unsigned Integers



Let's Think Now

A **signed** integer is a negative, 0, or positive integer. How can we represent both negative *and* positive numbers in binary?

Recap

- Getting Started With C
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Next Time on COMP201

- Make sure to reboot Boeing Dreamliners [every 248 days](#)
- Comair/Delta airline had to [cancel thousands of flights](#) days before Christmas
- Many operating systems [may have issues](#) storing timestamp values beginning on Jan 19, 2038
- [Reported vulnerability CVE-2019-3857](#) in libssh2 may allow a hacker to remotely execute code

Next time: *More on how a computer represents integer numbers? What are the limitations?*