

# CS107 Lecture 1

## Welcome to CS107!

Reading:

[Course Syllabus](#)

*Bryant & O'Hallaron, Ch. 1 (skim – available on Canvas)*

[Honor Code and Collaboration Page](#)

# Plan for Today

- Introduction + Syllabus
- Unix
- C 101 (please review the skipped slides)
- Bits and Bytes

# Interactive Classes

- Please feel free to raise your hand at any time with a question!
- Questions and comments are encouraged and recommended :-)

# Asynchronous Questions

- Have questions outside of Lecture/Office Hours?
  - IntelliCopilot offers instant AI support
    - Monitored by the Course Staff for additional feedback
    - All discussion posts are class wide
    - Please make sure to review our AI collaboration policy
  - ED for questions that won't benefit from AI support
- NOTE: All posts are not anonymous to course staff



# Asynchronous Questions

- Access Ed through Canvas
- Access IntelliCopilot at <https://edu.intellicopilot.com/>
  - Accounts for CS 107 Students are Free 😊 !
    - You will receive an email invite!





# CS107 Goals

Achieve **competence** in...

- writing C programs w/ memory and pointers
- translating C to/from assembly
- writing programs that respect limitations of computer arithmetic
- identifying bottlenecks + improving runtime performance
- working effectively in UNIX development environment





# Meet the Instructors



**Adam Keppler**  
(Co-Instructor)  
akeppler@stanford.edu



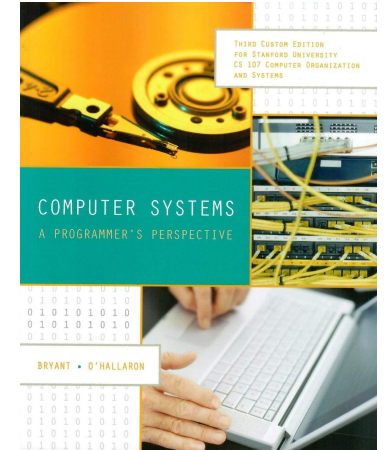
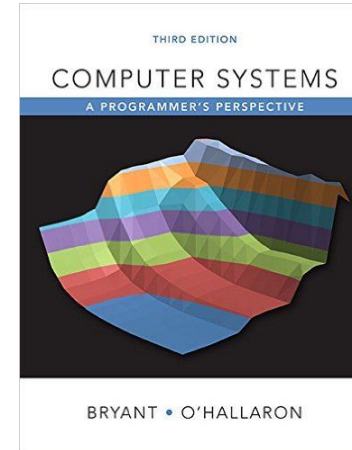
**Yasmine Alonso**  
(Co-Instructor)  
yalonso@stanford.edu



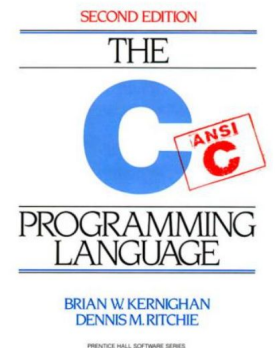
**Sudharsan Sundar**  
(Head Course Assistant)  
sjsundar@stanford.edu

# Textbook(s)

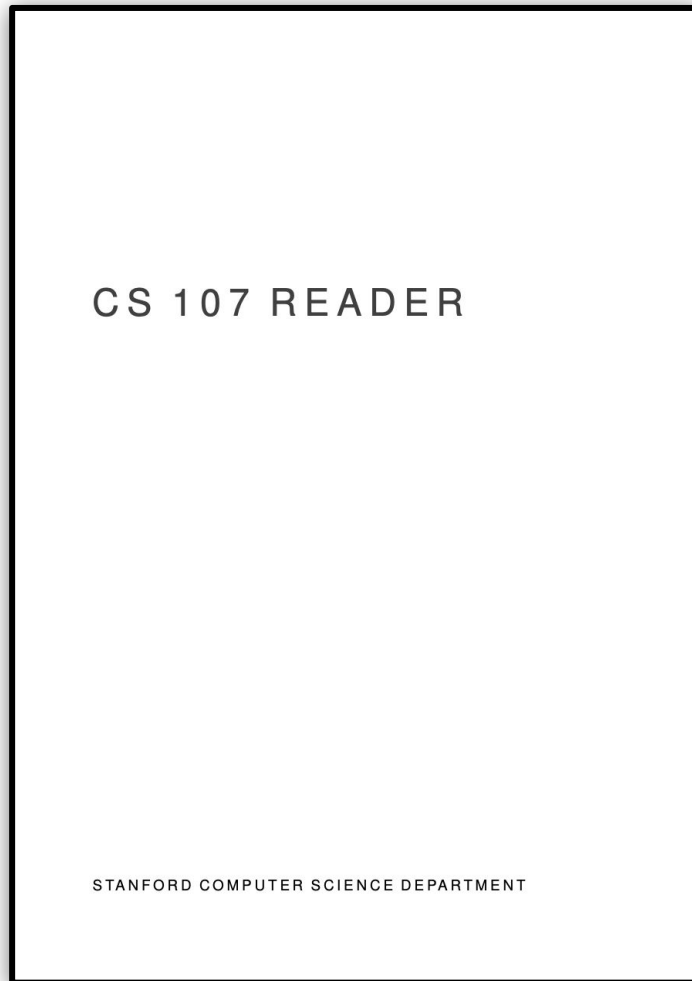
- *Computer Systems: A Programmer's Perspective* by Bryant & O'Hallaron, **3<sup>rd</sup> Edition**
  - **3<sup>rd</sup> edition matters** – important updates to content
  - Stanford Library has generously scanned **all** readings for CS107 under “fair use” (private study, scholarship, research). [**Canvas -> Files**]. Please do not distribute.
  - If you want more context, you may want to purchase a full copy
- A C programming reference of your choice
  - *The C Programming Language* by Kernighan and Ritchie (free link on course website Resources page)
  - Other C programming books, websites, or reference sheets



The textbooks are a **very** good resources in this course!




# CS107 Course Reader



- Condenses much of the material covered in this course!
- If you find any typos, let us know :)
- <https://stanford.edu/~cgregg/cgi-bin/107-reader>

# Course Structure

- **Lectures:** understand concepts, see demos
- **Assignments:** build programming skills, synthesize lecture/lab content
- **Labs:** learn tools, study code, discuss with peers  **Great preview of homework!**

# Course Overview

- 1. Bits and Bytes** - *How can a computer represent integer numbers?*
- 2. Chars and C-Strings** - *How can a computer represent and manipulate more complex data like text?*
- 3. Pointers, Stack and Heap** – *How can we effectively manage all types of memory in our programs?*
- 4. Generics** - *How can we use our knowledge of memory and data representation to write code that works with any data type?*
- 5. Assembly** - *How does a computer interpret and execute C programs?*
- 6. Heap Allocators** - *How do core memory-allocation operations like malloc and free work?*

# Grading

\*\*\*\*

40%

Quizzes

\*\*

20%

Final Exam

\*\*

20%

Assignments

\*\*

15%

Midterm Exam

\*

5%

Lab Participation

# Assignment Late Policy

- Assignments will typically be due on **Fridays at 11:59PM**
- Each assignment (except Assign6) will have a 48-hour grace period (so, submit up through Sunday at 11:59PM for full credit)
- Beyond this, assignments will not be accepted (except OAE extensions). If you face unforeseen circumstances, reach out to the teaching team so we can help you!

## Exceptions:

- Assign0 no cap on late submission
- Assign6 no late submissions accepted

# OAE Accommodations

If you have OAE accommodations, please fill out [this form!](#)

This is also on our Week 1 Ed Announcement!

# Weekly Ed Announcements

- Each week, we will post announcements (blasted to email) with important updates for the week (deadlines, exam logistics, etc.)
- First one posted after lecture today!
- **Please monitor these posts diligently so that you are caught up with everything you need to know for the week!**



# Stanford Honor Code

- The **Honor Code** is an undertaking of the students, individually and collectively:
  - that they will not give or receive aid in examinations; that they will not give or receive unpermitted aid in class work, in the preparation of reports, or in any other work that is to be used by the instructor as the basis of grading;
  - that they will do their share and take an active part in seeing to it that others as well as themselves uphold the spirit and letter of the Honor Code.
- The faculty on its part manifests its confidence in the honor of its students by refraining from proctoring examinations and from taking unusual and unreasonable precautions to prevent the forms of dishonesty mentioned above. The faculty will also avoid, as far as practicable, academic procedures that create temptations to violate the Honor Code.
- While the faculty alone has the right and obligation to set academic requirements, the students and faculty will work together to establish optimal conditions for honorable academic work.

see also: <http://honorcode.stanford.edu/>

**It is your responsibility to ensure you have read and are familiar with the honor code guidelines posted on the main page of the CS107 course website. Please read them and come talk to us if you have any questions or concerns.**

# Honor Code and CS107

- Please help us ensure academic integrity:
  - Indicate any assistance received on HW (books, friends, internet, ChatGPT, etc.).
  - Do not look at other people's solution code or answers
  - Do not give your solutions to others or post them on the web or our ED forum.
  - Report any inappropriate activity you see performed by others.
- Assignments are checked regularly for similarity with help of software tools.
- If you need help, please contact us and we will help you.
  - We do not want you to feel any pressure to violate the Honor Code in order to succeed in this course.
  - If you realize that you have made a mistake, you may retract your submission to any assignment at any time, no questions asked.

<https://cs107.stanford.edu/collaboration>

# Always Cite your Sources


- The world has an increasing number of resources available from:
  - Documentation
  - Stack Overflow
  - ChatGPT
  - Medium
  - And More
- Increasingly important to cite sources!
- Please tag sources that you used either in the README or top of the relevant file.
- Note: you ***do not*** need to cite usage of IntelliCopilot!

# AI Usage Policy

- We understand that AI is becoming more and more prevalent in our world (by all of us, in industry, etc.)
- We don't want to prohibit usage of these helpful tools, but we do strongly believe that many fundamentals for CS107 are critical to understand deeply.
- **Please do not use any AI tools to generate code.** Treat code generated by AI just like code generated by a friend. Use of AI for this purpose is considered a violation of the honor code.
- It is okay to use AI to ask conceptual questions on assignments/lectures/content!
- Again, cite any usage of AI tools for assignments (unless it's IntelliCopilot!)
- Read more about our policy (in the syllabus) [here](#) and [here](#)!

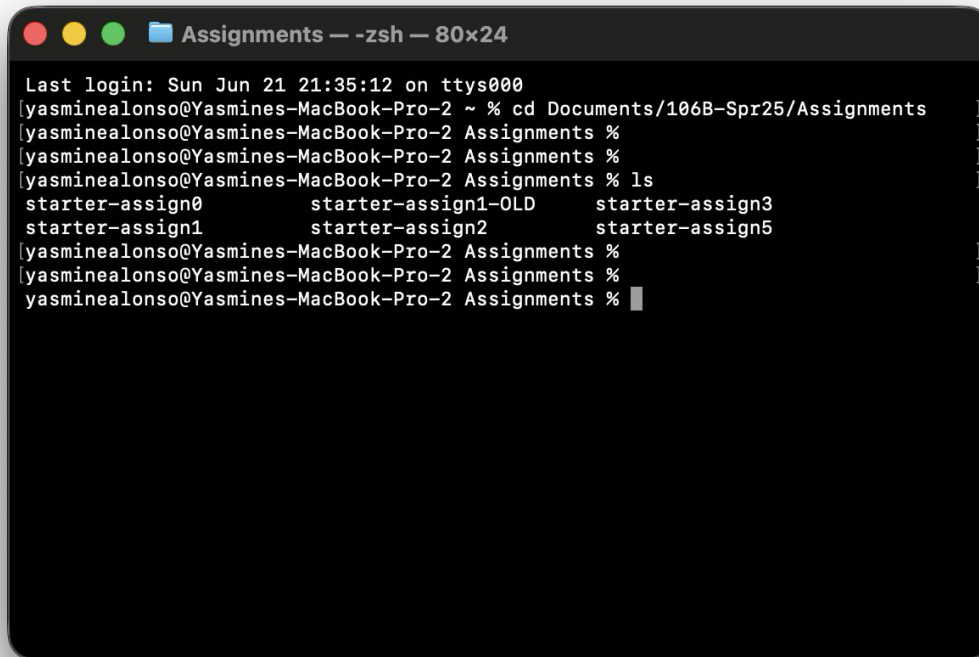
# Quizzes

**In-Class Attendance** is required for all non-CGOE students!

- During most lectures, we will have short in-person, pen and paper quizzes
- Designed to be low stress – each worth a very small portion of your grade!
- Lowest quiz will be dropped when determining your final course grade
- Please bring a pen/pencil/eraser to each class  !
- Our first quiz will take place on **Friday** in class.

# What is Unix?

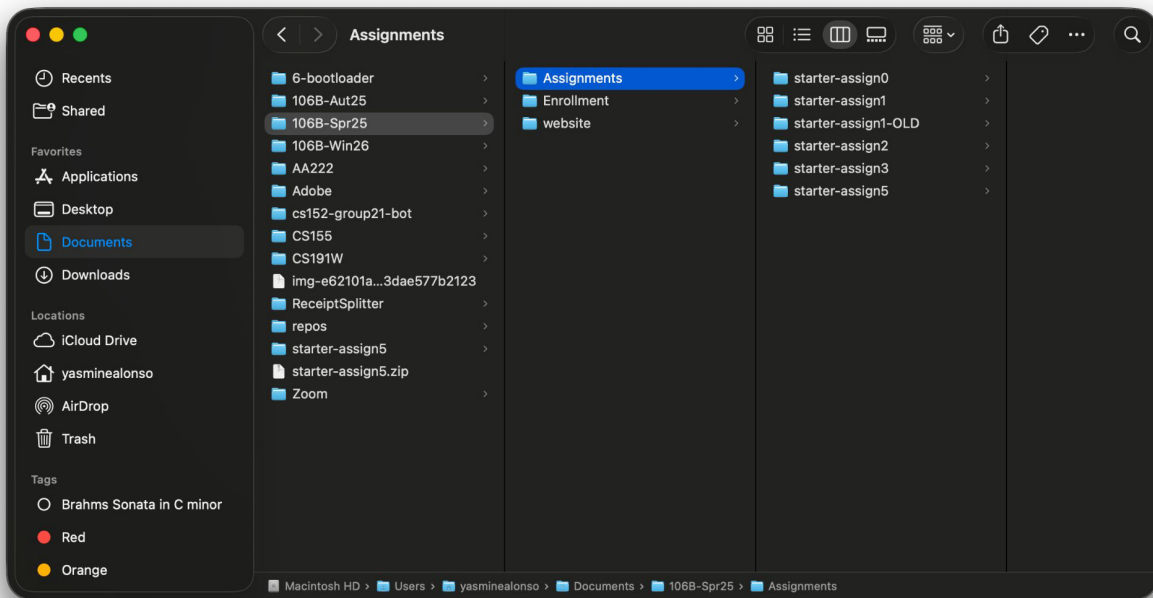
- **Unix**: a set of standards and tools commonly used in software development.
  - **macOS** and **Linux** are operating systems built on top of Unix
- You can navigate a Unix system using the **command line** (“terminal”)
- Every Unix system works with the same tools and commands

A terminal window titled "Assignments -- zsh -- 80x24" showing a user logging in and navigating to a directory. The user's name is yasminealonso and the machine is Yasmines-MacBook-Pro-2. The user runs 'cd Documents/106B-Spr25/Assignments', 'ls', and then 'ls' again. The output of the first 'ls' command shows a directory listing with files: starter-assign0, starter-assign1, starter-assign1-OLD, starter-assign2, starter-assign3, and starter-assign5. The terminal prompt is always yasminealonso@Yasmines-MacBook-Pro-2 Assignments %.

```
Assignments -- zsh -- 80x24
Last login: Sun Jun 21 21:35:12 on ttys000
yasminealonso@Yasmines-MacBook-Pro-2 ~ % cd Documents/106B-Spr25/Assignments
yasminealonso@Yasmines-MacBook-Pro-2 Assignments %
yasminealonso@Yasmines-MacBook-Pro-2 Assignments %
yasminealonso@Yasmines-MacBook-Pro-2 Assignments % ls
starter-assign0      starter-assign1-OLD  starter-assign3
starter-assign1      starter-assign2      starter-assign5
yasminealonso@Yasmines-MacBook-Pro-2 Assignments %
yasminealonso@Yasmines-MacBook-Pro-2 Assignments %
yasminealonso@Yasmines-MacBook-Pro-2 Assignments %
```

# What is the Command Line?

- The **command-line** is a text-based interface (i.e., **terminal** interface) to navigate a computer, instead of a Graphical User Interface (GUI).



Graphical User Interface

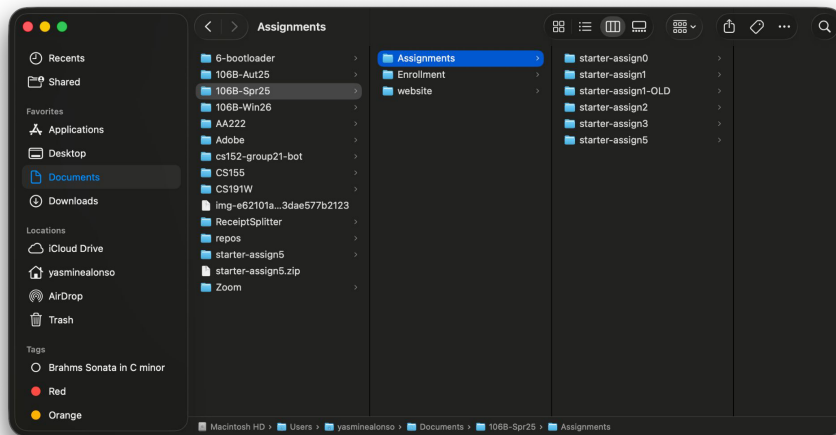
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[yasminealonso@Yasmines-MacBook-Pro-2 ~ % cd Documents/106B-Spr25/Assignments ]
[yasminealonso@Yasmines-MacBook-Pro-2 Assignments % ]
[yasminealonso@Yasmines-MacBook-Pro-2 Assignments % ]
[yasminealonso@Yasmines-MacBook-Pro-2 Assignments % ls ]
starter-assign0      starter-assign1-OLD  starter-assign3
starter-assign1      starter-assign2      starter-assign5
[yasminealonso@Yasmines-MacBook-Pro-2 Assignments % ]
[yasminealonso@Yasmines-MacBook-Pro-2 Assignments % ]
[yasminealonso@Yasmines-MacBook-Pro-2 Assignments % █
```

Text-based interface

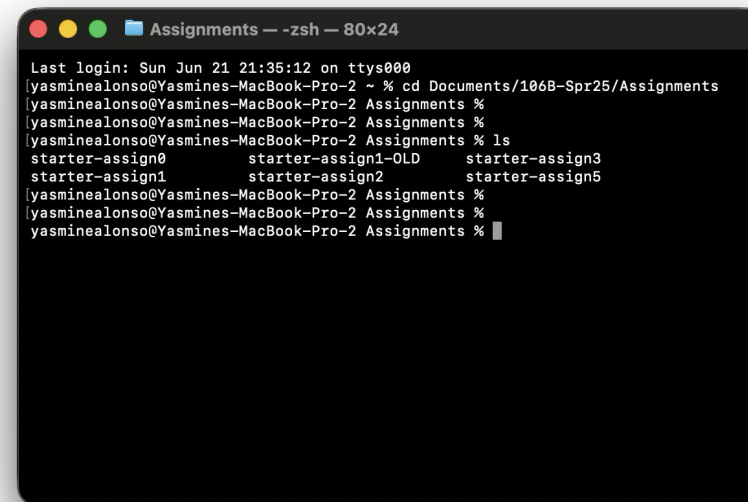
# Command Line vs. GUI

Just like a GUI file explorer interface, a terminal interface:

- shows you a **specific place** on your computer at any given time.
- lets you go **into folders** and **out of folders**.
- lets you **create new files** and **edit files**.
- lets you **execute programs**.



Graphical User Interface



Command-line interface

# Why use Unix/the Command Line?

- You can navigate almost any device using the same tools and commands:
  - Servers
  - Laptops and desktops
  - Embedded devices (Raspberry Pi, etc.)
  - Mobile Devices (Android, etc.)
- Used frequently by software engineers:
  - **Web development:** running servers and web tools on servers
  - **Machine learning:** processing data on servers, running algorithms
  - **Systems:** writing operating systems, networking code and embedded software
  - **Mobile Development:** running tools, managing libraries
  - And more...
- We'll use Unix and the command line to implement and execute our programs.

# Unix Commands to Try

- **cd** – change directories (..)
- **ls** – list directory contents
- **mkdir** – make directory
- **vim** – open text editor
- **rm** – remove file or folder
- **man** – view manual pages

See the course website for more commands and a complete reference.

# Learning Unix and the Command Line

- Using Unix and the command line can be intimidating at first:
  - It looks retro!
  - How do I know what to type?
- It's like learning a new language:
  - At first, you may have to constantly look things up (**resources** on course website!)
  - It's important to spend as much time as possible (during labs and assignments) building muscle memory with the tools

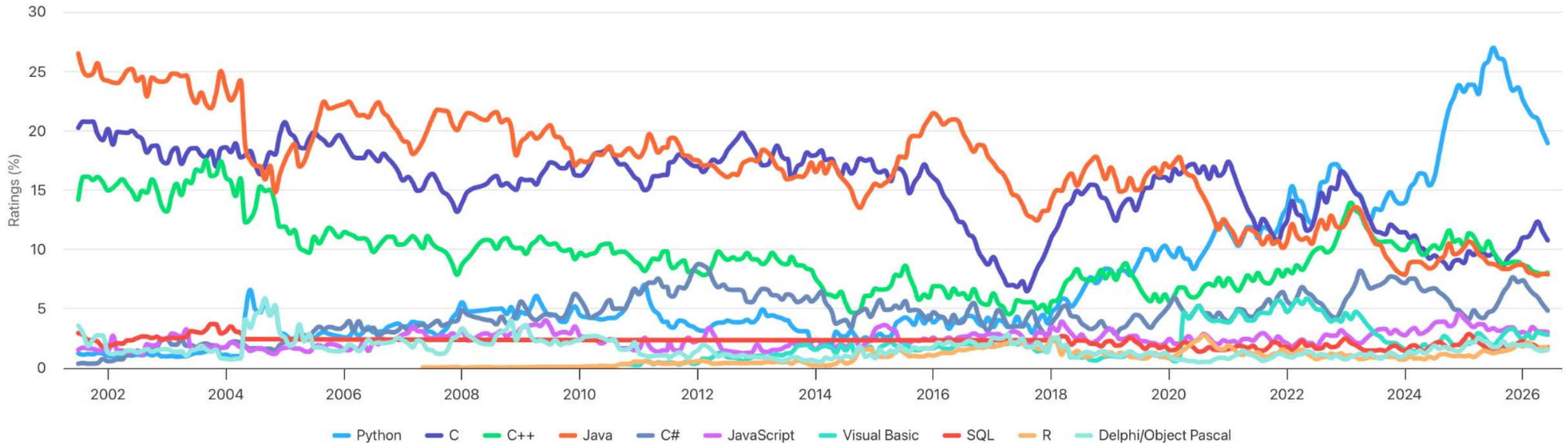
# Plan for Today

- Introduction + Syllabus
- Unix?
- C 101 (please review the skipped slides)
- Bits and Bytes

# Programming Language Popularity

TIOBE Programming Community Index

Source: www.tiobe.com



- C is once again the 2<sup>nd</sup> most popular language!
- Between 1988-2024, was the most popular/2<sup>nd</sup> most popular language.
- Surpassed C++ in late 2025!

# Programming Language Popularity

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- Surpassed C++ in late 2025!

# The C Language History

- Birthdate around 1970
- Created to make writing Unix (the OS itself) and tools for Unix easier
- Common ancestor to most programming languages
  - Especially C++/Java family of languages
- Design principles:
  - Small, simple abstractions of hardware
  - Minimalist aesthetic
  - C focuses on: **efficiency and minimalism**
  - C sacrifices: safety and convenient high-level services and abstractions
- As the common ancestor, it helped inspire safer systems, increased abstraction and higher level features!

# C vs. C++ and Java

## They all share:

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

## C Limitations:

- No advanced features like operator overloading, default arguments, pass by reference, classes and objects, Abstract Data Types, etc.
- Standard Libraries offer core functionality rather than nice wrappers or syntactic sugar.
- Small language means small footprint on a system.
- No runtime checks (this may cause severe security vulnerabilities and bugs! )

# Programming Philosophies

**Functional Programming (FP)** – Programming philosophy that seeks to *avoid using state*, preferring functions with no side effect, data immutability, and thread-safe code.

C supports some functional elements, but is not a functional programming language (FPL).

**Procedural Programming (PP)** – About creating procedures or ‘scripts’ using functions to setup a series of tasks or steps to complete.

C is consider the quintessential Procedural Programming Language.

**Object Oriented Programing (OOP)** – Create *objects* that contain and maintain both data and code in the form of *fields* (attributes/methods). There are also interactions between the objects such as inheritance, encapsulation, abstraction, and polymorphism.

Unlike Python/C++/Java, C is **not** an Object Oriented Language and does not have a notion of objects.

# 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.**

**Programming Philosophy is a Spectrum:** Most major languages have elements of multiple philosophies, while some occasionally epitomize a specific philosophy.

## Quintessential Examples:

LISP - Functional Programming

Java - Object Oriented Programming

C – Procedural Programming

# 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.
- Modern alternatives to C are emerging (e.g., Rust), but they're more complicated and not quite ready for those new to systems programming (but talk to us outside of class to learn more if interested!)

# The Heart of C

- C helps those who help themselves!
- C is meant to give fundamental tools that expose the computer's internal workings as much as possible, without becoming Assembly
- As such C is fundamentally about data, its storage, and its manipulation
  - Every program is technically data itself, with C it is possible to write self-editing programs
- There are **no objects** in C, only data
- Types in C is an illusion meant to provide convenience to the user and help with organization

# Types in C: Static & Strong Typing

- A type in C defines how much memory is stored with the associated data
- It also defines whether the value is raw data or a 'pointer' to another location in memory
  - We will talk extensively more about pointers in the coming weeks.
- For now, let's take a look at the fundamental non-pointer types:
  - **int** – records an integer value ( ..., -3, -2, -1, 0, 1, 2, 3 , ...) in binary
  - **float** – records a decimal value ( -0.3, 0, 0.3 , 1.0, 3.14, etc.) in binary
    - If you are wondering how this happens, it is a great question! We will cover it in a later section
  - **char** – Any English letter (uppercase, lowercase, numbers, and some control codes)
  - **bool** – Technically as small as a single bit 0 or 1, compilers sometimes store it as a char due to restrictions on byte-alignment of memory
- While the above are the core types, they come in different flavors. Flavors are arranged by:
  - **How much room**, you have to store the information (it takes more room to store 1024 than 4)
  - **Storage Format**, is the value always positive? Do you need a negative? A Decimal?
  - **Does it hold data or point to data?** (Pointers)

# Assignment 0

Assign 0: out today and due **Friday 6/26!**

Note: Short turn-around to make the rest of the quarter easier

Need more time? *We're lenient with A0 deadline, just submit ASAP.*

Need help on C syntax or writing C code? *Come to OH, post on Ed, or ask IntelliCopilot!*

- Slides on website
- Lecture code on myth machines
- Office Hours (beginning Wednesday)
- IntelliCopilot
- Course textbook/course reader (posted on Canvas and linked here!)

# Your 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;  
}
```

# Your First C Program

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/*  
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```

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

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

## Program comments

You can write block or inline comments.

# Your 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;  
}
```

## Import statements

C libraries are written with angle brackets.

Local libraries have quotes:

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

# Your 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;  
}
```

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

# Your 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;  
}
```

**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)

# Your First C Program

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

**printf** – prints output to the screen

# Console Output: printf

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

`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)

```
// Example
```

```
char *classPrefix = "CS";
```

```
int classNumber = 107;
```

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

```
// You are in CS107
```

# 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;
}
```

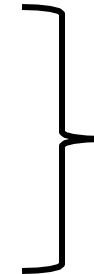
# Writing, Debugging, and Compiling

We will use:

- the **vim** 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



Now



Next week

# Working on C Programs

- **ssh** – remotely log in to Myth computers
- **Vim** – text editor to write and edit C programs
  - Use the mouse to position cursor, scroll, and highlight text
  - Ctl-x Ctl-s to save, 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 code is accessible at  
**/afs/ir/class/cs107/lecture-code/lect[N]**
  - Make your own copy: **cp -r /afs/ir/class/cs107/lecture-code/lect[N] lect[N]**
  - See the website for even more commands, and a complete reference.

# Assignment 0

Assignment page: <https://web.stanford.edu/class/cs107/assign0/>

Assignment released soon, due **Friday, June 26th**

# Lab Sign Up

Preference form is now open!

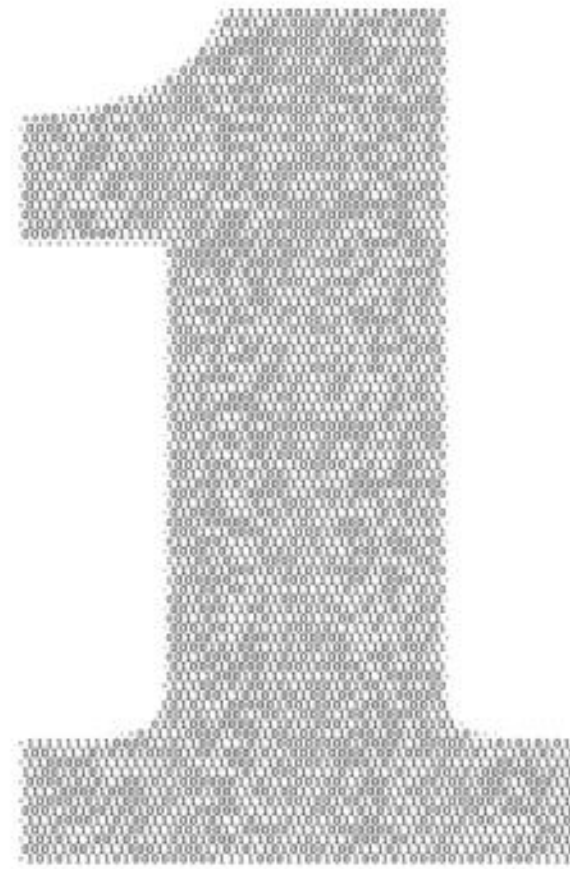
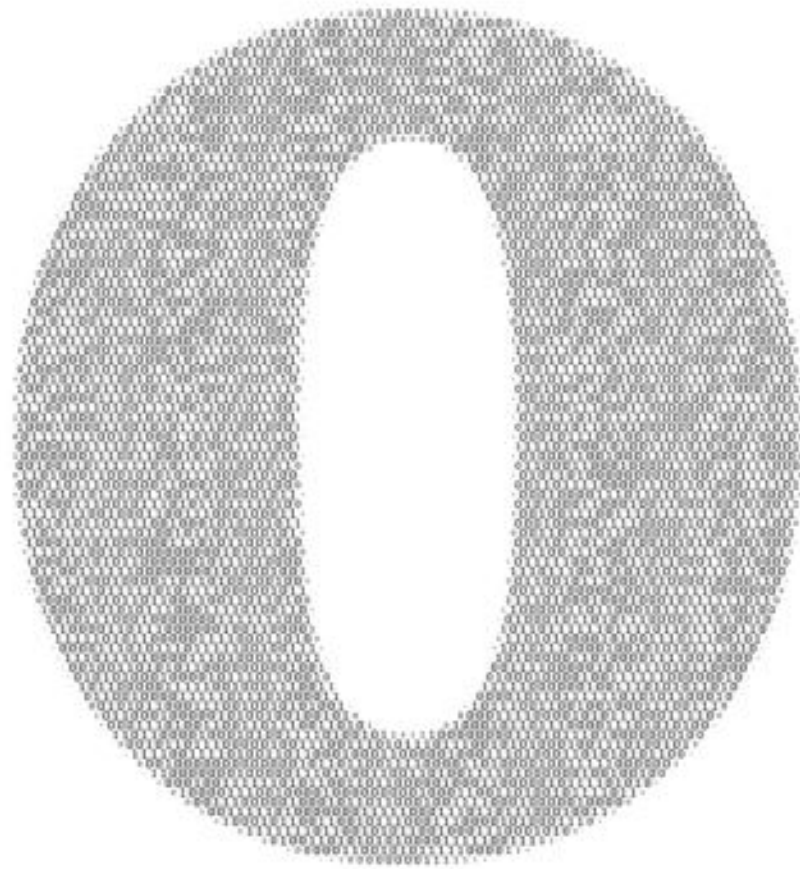
Labs will begin week this week (Thursday/Friday)!

Lab signup is based on submitted preferences, otherwise you'll be assigned. Please submit by this tomorrow.

# Plan for Today

- Introduction + Syllabus
- Unix?
- C 101 (please review the skipped slides)
- **Bits and Bytes**

# Bits

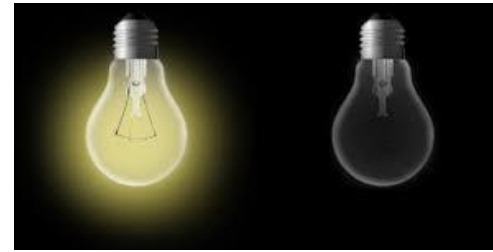


# Computers are good at detecting "on" or "off"

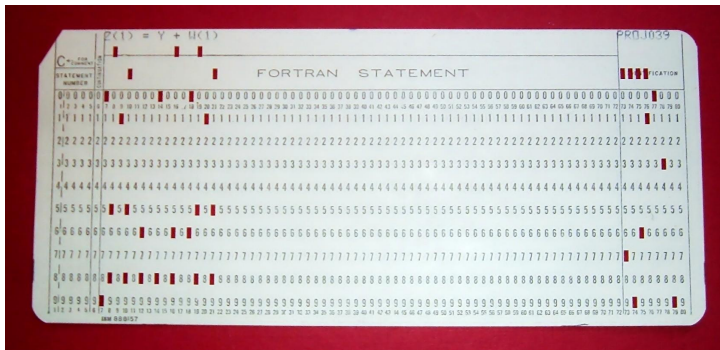
We have lots of ways to tell the difference between two different states:



Clockwise / Counterclockwise



Lightbulb off / on



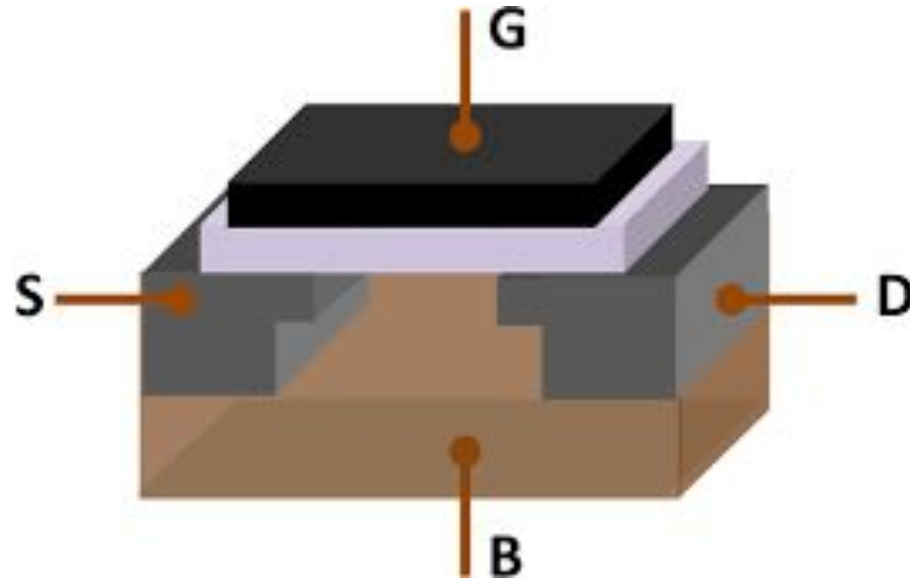
Punchcard hole / no hole

And many more...

- True or False
- Yes or No
- Door locked / unlocked
- etc!

# Computers are good at detecting "on" or "off"

Electronic computers are built using transistors. A transistor can be set up to either be "off" or "on" -- this gives us our 0 and 1!



Computers are built around the idea of two states: "**on**" and "**off**". Transistors implement 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...

# How does a Bit do so much?

- Information can be reshaped
- Numbers can have the same value but in different representations
- Typically, we use base 10 in everyday life (most people attribute this to humans having 10 fingers, but humans have used other # systems)
- Base 10 has ten digits: **0 1 2 3 4 5 6 7 8 9**
- Base 2 has two digits: **0 1**
- We can represent up to **ten** numbers with one digit in base 10
- We can represent up to **two** numbers with one digit in base 2
- If we want to represent more numbers, we add more digits regardless of the base.

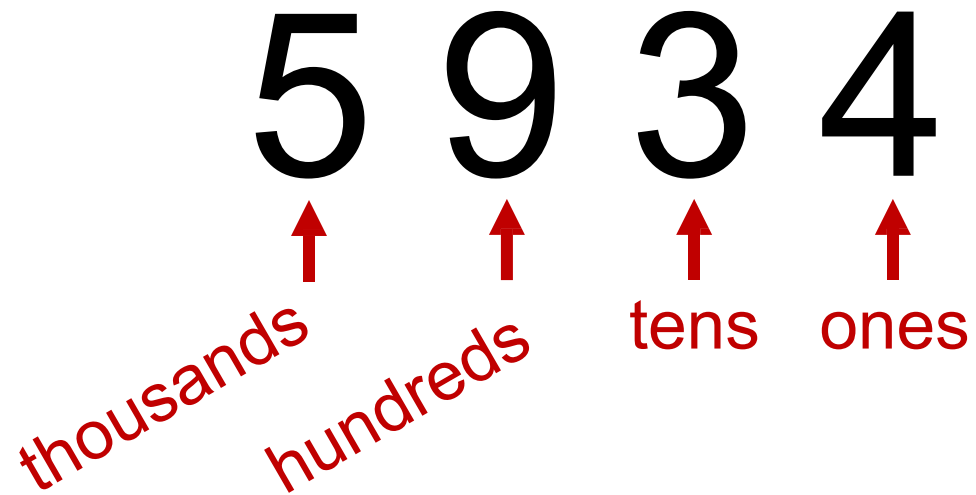
# Base 10

5 9 3 4

Digits 0-9 (*base-10*)

4 Columns

# Base 10



$$= 5 \cdot 1000 + 9 \cdot 100 + 3 \cdot 10 + 4 \cdot 1$$

# Base 10

5 9 3 4

↑ ↑ ↑ ↑

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

$$= 5 \cdot 10^3 + 9 \cdot 10^2 + 3 \cdot 10^1 + 4 \cdot 10^0$$

# 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 (*base-2*)

# Base 2

1 0 1 1

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

$$= 1 \cdot 2^3 + 0 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0 = 11_{10}$$

# Base 2

Most significant bit (MSB)

Least significant bit (LSB)



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?

- 2 Strategies:

1. Build the number from the left (Find the **most** significant bit first)
2. Build the number from the right (Find the **least** significant bit first)

# Base 10 to Base 2: **MSB** First

**Question:** What is 6 in base 2?

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

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

# Base 10 to Base 2: **MSB** First

**Question:** What is 6 in base 2?

• Strategy:

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

0	1		
—	—	—	—
$2^3$	$2^2$	$2^1$	$2^0$

# Base 10 to Base 2: **MSB** First

**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  $2 \leq 6 - 2^2$ ?

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# Base 10 to Base 2: **MSB** First

**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  $2 \leq 6 - 2^2$ ?  $2^1 = 2$
- $6 - 2^2 - 2^1 = 0$ !

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

# Base 10 to Base 2: LSB First

**Question:** What is 6 in base 2?

- Strategy:
  - What is  $6 \% 2$ ?
  - What is  $6 // 2$ ?

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





# Base 10 to Base 2: **LSB First**

**Question:** What is 6 in base 2?

- Strategy:
  - What is  $1 \% 2$ ? **1**
  - What is  $1 // 2$ ? **0** – Stop when the integer divide returns 0

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

# Base 10 to Base 2: LSB First

**Question:** What is 6 in base 2?

- Strategy:
  - Add leading 0s as needed

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

# 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**

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2<sup>x</sup>:

1

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11111111

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1

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

7 6 5 4 3 2 1 0

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

- **Strategy 2:**  $2^8 - 1 = 255$

7 6 5 4 3 2 1 0

# Byte Values

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- **Strategy 2:**  $2^{16} - 1 = 65,535$

# Byte Values

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**minimum = 0    maximum = 65,535**
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- **Strategy 2:**  $2^{16} - 1 = 65,535$

# 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!

NOTE: Inverse is also true, multiplying by the base adds a 0

# Dividing by Base

$$1450 / 10 = 145$$

$$1100_2 / 2 = 110$$

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

NOTE: Inverse is also true, dividing by the base removes a column

# Combinations of Bits Can: Encode Anything! Represent Everything!

## ASCII Code: Character to Binary

0	0011 0000	O	0100 1111	m	0110 1101
1	0011 0001	P	0101 0000	n	0110 1110
2	0011 0010	Q	0101 0001	o	0110 1111
3	0011 0011	R	0101 0010	p	0111 0000
4	0011 0100	S	0101 0011	q	0111 0001
5	0011 0101	T	0101 0100	r	0111 0010
6	0011 0110	U	0101 0101	s	0111 0011
7	0011 0111	V	0101 0110	t	0111 0100
8	0011 1000	W	0101 0111	u	0111 0101
9	0011 1001	X	0101 1000	v	0111 0110
A	0100 0001	Y	0101 1001	w	0111 0111
B	0100 0010	Z	0101 1010	x	0111 1000
C	0100 0011	a	0110 0001	y	0111 1001
D	0100 0100	b	0110 0010	z	0111 1010
E	0100 0101	c	0110 0011	.	0010 1110
F	0100 0110	d	0110 0100	,	0010 0111
G	0100 0111	e	0110 0101	:	0011 1010
H	0100 1000	f	0110 0110	;	0011 1011
I	0100 1001	g	0110 0111	?	0011 1111
J	0100 1010	h	0110 1000	!	0010 0001
K	0100 1011	I	0110 1001	'	0010 1100
L	0100 1100	j	0110 1010	"	0010 0010
M	0100 1101	k	0110 1011	{	0010 1000
N	0100 1110	l	0110 1100	}	0010 1001
				space	0010 0000

We can encode anything we want with bits. E.g., the ASCII character set.

Questions?