The Hardware/Software Interface

CSE 351 Autumn 2022

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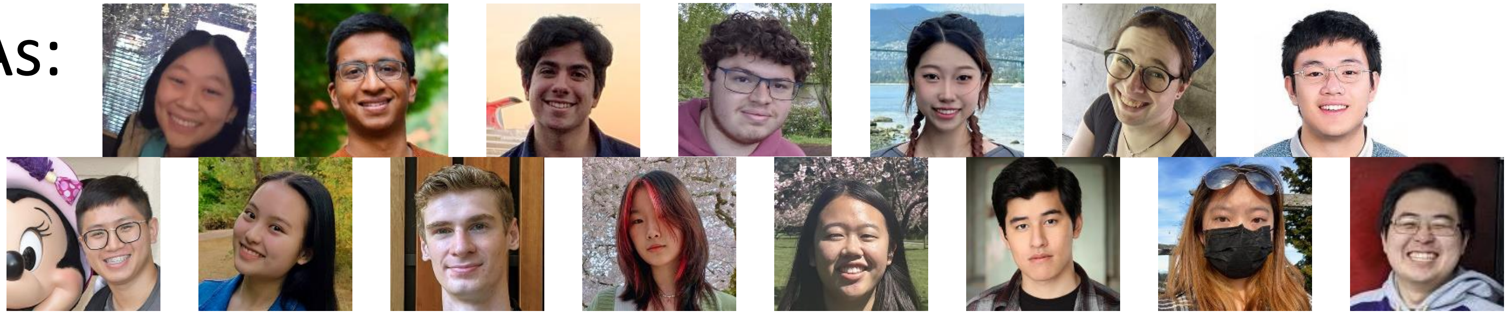
http://xkcd.com/676/

Lecture Outline

- **Course Introduction**
- Course Policies
  - https://courses.cs.washington.edu/courses/cse351/22au/syllabus.html
- Binary and Numerical Representation

Introductions: Course Staff

- Instructor: just call me Justin
  - CSE Associate Teaching Professor
  - Raising a toddler this quarter, will be tired
- TAs:



  - Available in section, office hours, and on Ed Discussion
- More than anything, we want you to feel…
  - ✓ Comfortable and welcome in this space
  - ✓ Able to learn and succeed in this course
  - ✓ Comfortable reaching out if you need help or want change

Introductions: You!

- ~320 students registered, split across two lectures
- CSE majors, ECE majors, and more
  - Most of you will find almost everything in the course new
  - Many of you are new to CSE and/or UW (and campus)!
- Get to know each other! Help each other out!
  - Science says that learning happens best in groups
  - Working well with others is a valuable life skill
  - Diversity of perspectives expands your horizons
  - Take advantage of group work, where permissible, to *learn*, not just get a grade

Welcome to CSE351!

- Our goal is to teach you the key abstractions "under the hood"
  - How does your source code become something that your computer understands?
  - What happens as your computer is executing one or more processes?

Layers of Computing Below Programming

Software Applications
(written in Java, Python, C, etc.)

Programming Languages & Libraries
(*e.g.*, Java Runtime Env, C Standard Lib)

OS/App interface

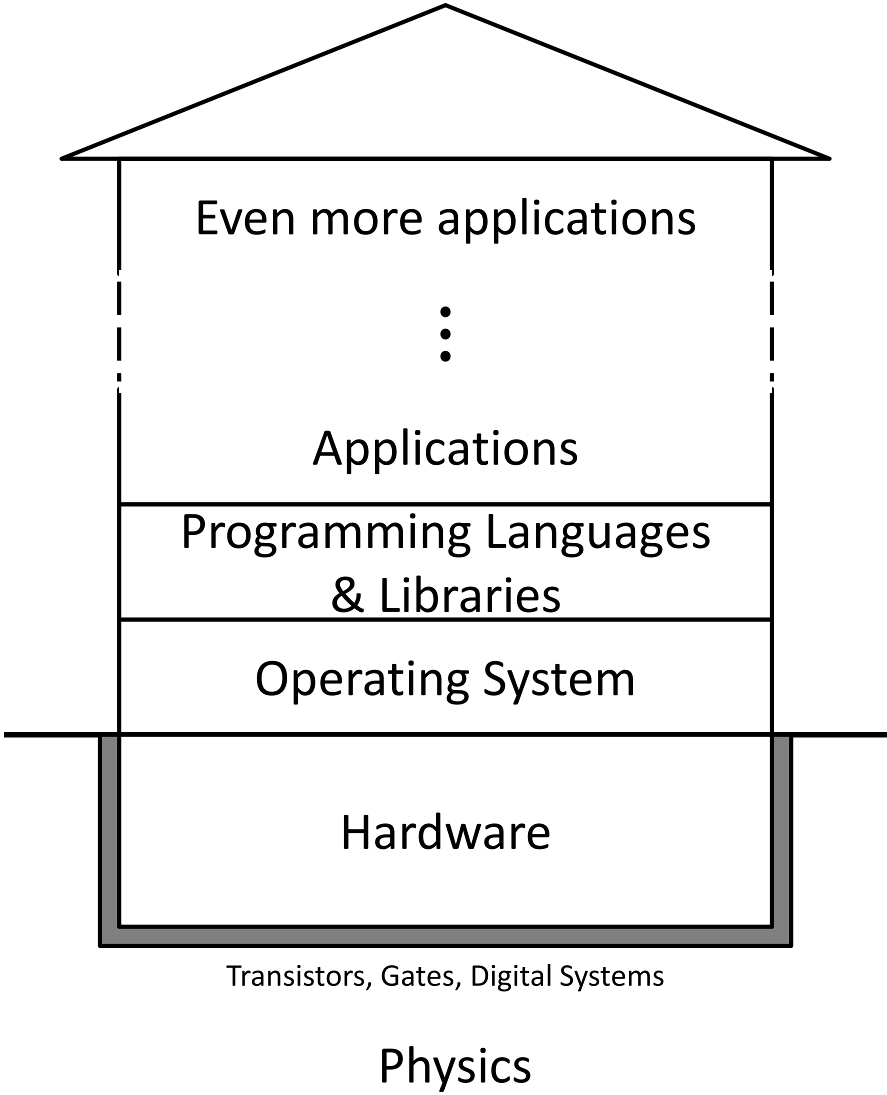
Operating System
(*e.g.*, Linux, MacOS, Windows)

HW/SW interface

Hardware
(*e.g.*, CPU, memory, disk, network, peripherals)

"House" of Computing Metaphor

- We continue to build upward but everything relies on the base & foundation
  - We'll explore parts of Hardware, OS, and PL
- Built a long time ago
  - Some parts have been updated over the years, some have not
  - More remodeling necessary, but should understand *how* and *why* things are this way before demolishing anything



The Hardware/Software Interface

- Topic Group 1: **Data**
  - Memory, Data, Integers, Floating Point, Arrays, Structs
- Topic Group 2: **Programs**
  - x86-64 Assembly, Procedures, Stacks, Executables
- Topic Group 3: **Scale & Coherence**
  - Caches, Processes, Virtual Memory, Memory Allocation

- Learning in this class
  - You might miss Java, but we just ask you to keep your heart open; something unexpected might pique your interest!
  - Notice and nurture any wants to linger in some space
    - Many future classes to explore this space more

Some fun topics that we will touch on

- Which of the following seems the most interesting to you? (vote in Ed Lessons)

a) What is a GFLOP and why is it used in computer benchmarks?
b) How and why does running many programs for a long time eat into your memory (RAM)?
c) What is stack overflow and how does it happen?
d) Why does your computer slow down when you run out of *disk* space?
e) What was the flaw behind the original Internet worm, the Heartbleed bug, and the Cloudbleed bug?
f) What is the meaning behind the different CPU specifications? (*e.g.*, # of cores, size of cache)

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- **Course Policies**
  - https://courses.cs.washington.edu/courses/cse351/22au/syllabus.html
- Binary and Numerical Representation

Bookmarks

- Website: https://courses.cs.washington.edu/courses/cse351/22au/
  - Schedule, policies, materials, videos, assignment specs, etc.
- Ed Course: https://edstem.org/us/courses/23927
  - Discussion: announcements, ask and answer questions
  - Lessons: readings, lecture questions, homework
  - Resources: links to other tools and information
- Linked from website and Ed
  - Canvas: surveys, grade book, Zoom links
  - Gradescope: lab submissions, take-home exams
  - Panopto: lecture recordings

Grading

- **Pre-lecture Readings:** 5%
  - Can reveal solution after one attempt (completion)
- **Homework:** 20% total
  - Unlimited submission attempts (autograded correctness)
- **Labs:** 40% total
  - Last submission graded (correctness)
- **Exams:** Midterm (16%) and Final (16%)
  - Take-home; individual, but some discussion permitted
- **EPA:** Effort, Participation, and Altruism (3%)

Group Work in 351

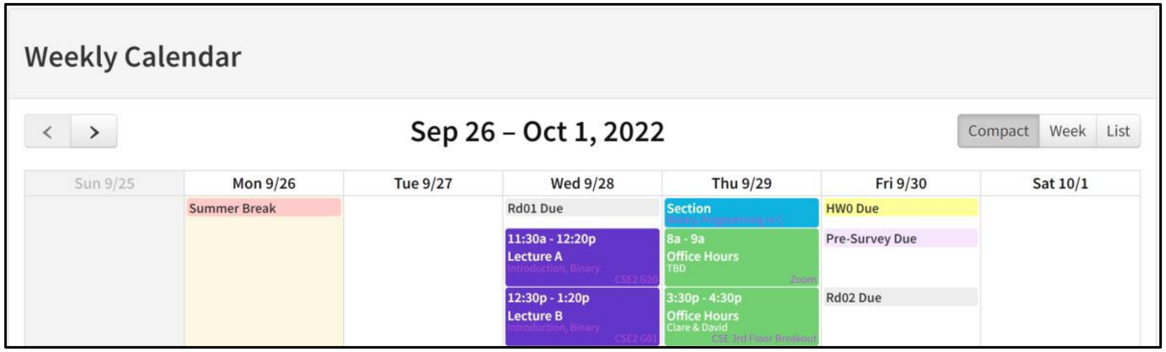
- Group work will be *emphasized* in this class
  - Lecture and section will have built-in group work time – you will get the most out of it if you actively participate!
    - TAs will circle around the room and interact with groups
    - Raise your hand to get the attention of a staff member
  - Most assignments allow collaboration – talking to classmates will help you synthesize concepts and terminology
    - *The major takeaways for this course will be the ability to explain the major concepts verbally and/or in writing to others*
  - However, the responsibility for learning falls on *you*

Lab Collaboration and Academic Integrity

- All submissions are expected to be yours and yours alone
- You are encouraged to discuss your assignments with other students (*ideas*), but we expect that what you turn in is yours
- It is NOT acceptable to copy solutions from other students or to copy (or start your) solutions from the Web (including Github, Chegg, and similar sites)
- Our goal is that *YOU* learn the material so you will be prepared for exams, interviews, and the future

Office Hours

- Check Weekly Calendar on website for scheduled office hours:



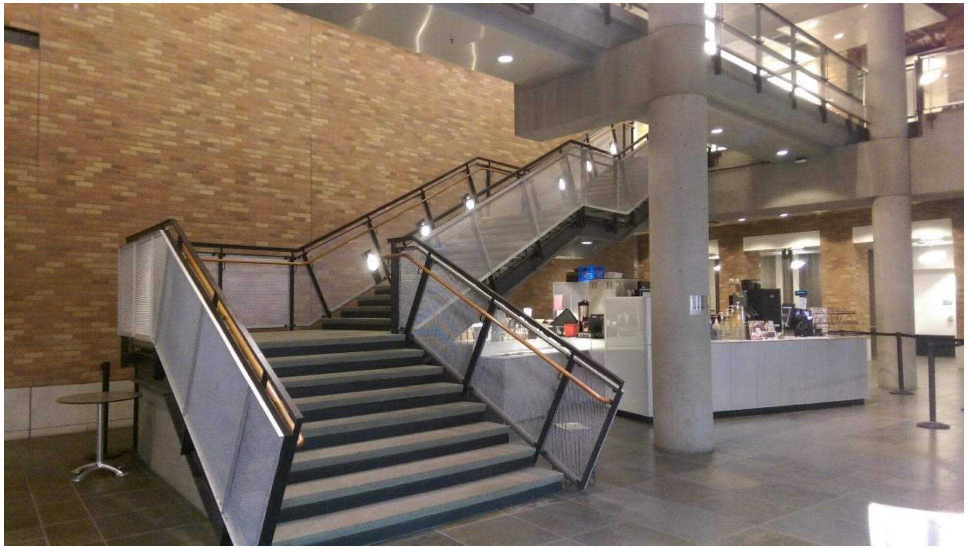
  - In-person or virtual, but NOT hybrid
  - Zoom meeting links found in Zoom tab within Canvas
- *All* office hours will use a Google Sheets queue:
  - Fill out first 3 columns to enter queue:

Name(s)	Category	Description	Time Queued	Staff	Status
Example 1	Concept	Question about floating point encoding range.		Justin	Done
Example 2	Debugging	Lab 5: running into a segfault in mm_malloc after reaching end of the heap.		Justin	Done
Example 3	Spec	Lab 1a: confusion over within same block examples		Justin	Done
Example 4	Tools	GDB: how do I examine memory on the stack?		Justin	Done

- We encourage you to chat with other students if the TAs are busy!

In-Person Office Hours

- Allen 3rd floor breakout
  - Up the stairs in the CSE Atrium (Allen Center, not Gates)



  - At the top of two flights, the open area with the whiteboard wall is the 3rd floor breakout!

Extensions, Accommodations, Help

- Extenuating circumstances
  - Students (and staff) face an extremely varied set of environments and circumstances
  - For formal accommodations, go through Disability Resources for Students (DRS)
  - We will try to be accommodating otherwise, but *the earlier you reach out*, the better

- Don’t suffer in silence – talk to a staff member!
  - We have a 1-on-1 meeting request form

To-Do List

- Admin
  - Explore/read the course website *thoroughly*
  - Check that you can access Ed Discussion & Lessons
  - **Get your machine set up to access the CSE Linux environment (CSE VM or attu) *as soon as possible***
  - Optionally, sign up for CSE 391: System and Software Tools
- Assignments
  - Pre-Course Survey and hw0 due Friday (9/30)
  - hw1 and Lab 0 due Monday (10/3)
  - Pre-lecture readings due before each lecture – 11 am

Lecture Outline

- Course Introduction
- Course Policies
  - Return to in-person instruction
  - https://courses.cs.washington.edu/courses/cse351/22au/syllabus.html
- **Binary and Numerical Representation**

Reading Review

- Terminology:
  - numeral, digit, base, symbol, digit position, leading zeros
  - binary, bit, nibble, byte, hexadecimal
  - numerical representation, encoding scheme

- Questions from the Reading?

Review Questions

- What is the *decimal value* of the numeral 107_8?
  A. 71
  B. 87
  C. 107
  D. 568

- What is the decimal number 108 in hex?
  A. 0x6C
  B. 0xA8
  C. 0x108
  D. 0x612

- Represent 0b100110110101101 in hex.

- Represent 0x3C9 in binary.

Base Comparison

- Why does all of this matter?
  - *Humans* think about numbers in **base 10**, but *computers* "think" about numbers in **base 2**
  - Binary encoding is what allows computers to do all of the amazing things that they do!
- You should have this table memorized by the end of the class
  - Might as well start now!

Base 10	Base 2	Base 16
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

Numerical Encoding

- **AMAZING FACT: You can represent *anything* countable using numbers!**
  - Need to agree on an encoding
  - Kind of like learning a new language

- Examples:
  - Decimal Integers: 0→0b0, 1→0b1, 2→0b10, etc.
  - English Letters: CSE→0x435345, yay→0x796179
  - Emoticons: 😃 0x0, 😔 0x1, 😎 0x2, 😇 0x3, 😈 0x4, 🙋‍♀️ 0x5

Binary Encoding

- With n binary digits, how many "things" can you represent?
  - Need n binary digits to represent N things, where $2^n \geq N$
  - Example: 5 binary digits for alphabet because $2^5 = 32 > 26$

- A binary digit is known as a bit
- A group of 4 bits (1 hex digit) is called a nibble
- A group of 8 bits (2 hex digits) is called a byte
  - 1 bit $\rightarrow$ 2 things, 1 nibble $\rightarrow$ 16 things, 1 byte $\rightarrow$ 256 things

So What's It Mean?

- *A sequence of bits can have many meanings!*

- Consider the hex sequence 0x4E6F21
  - Common interpretations include:
    - The decimal number 5140257
    - The real number 7.203034×10^{-39}
    - The characters "No!"
    - The background color of this slide

- It is up to the program/programmer to decide how to interpret the sequence of bits

Binary Encoding – Characters/Text

- ASCII Encoding (www.asciitable.com)
  - American Standard Code for Information Interchange

Dec	Hx	Oct	Char		Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL	(null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH	(start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX	(start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX	(end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT	(end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	[illegible]	[illegible]#100;	d
5	5	005	ENQ	(enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	[illegible]	[illegible]101;	e
6	6	006	ACK	(acknowledge)	38	26	046	&	&	70	46	106	F	F	102	[illegible]	[illegible]46	[illegible]102;	f
7	7	007	BEL	(bell)	39	27	047	'	'	71	47	107	[illegible]#71;	G	[illegible]	[illegible]	[illegible]47	[illegible]#103;	g
8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	[illegible]72	[illegible]	[illegible]	[illegible]	150	[illegible]104;	h
9	9	011	TAB	(horizontal tab)	41	29	051	)	)	73	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	i	i
10	A	012	LF	(NL line feed, new line)	42	2A	052	*	*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	j	j
11	B	013	VT	(vertical tab)	43	2B	053	&#43[illegible]	[illegible]	[illegible]	4B	[illegible]	[illegible]	[illegible]	107	6B	153	k	k
12	C	014	FF	(NP form feed, new page)	44	2C	0[illegible]	[illegible]#44[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]#76;	L	108	6C	154	l	l
13	D	015	CR	(carriage return)	45	2D	0[illegible]	[illegible]	-	[illegible]	[illegible]	115	M	M	109	6D	155	m	m
14	E	016	SO	(shift out)	[illegible]	2E	05[illegible]	[illegible]	.	[illegible]	4E	116	N	N	110	6E	156	n	n
15	F	017	SI	(shift in)	[illegible]	2F	057	[illegible]	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE	(data link escap[illegible]	[illegible]	[illegible]	060	[illegible]#48;	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1	(d[illegible]ice con[illegible]l)	[illegible]	[illegible]	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2	[illegible])	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	[illegible]	[illegible]	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	[illegible]	[illegible]24	[illegible]	[illegible] 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	[illegible]	[illegible]	[illegible] acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	[illegible]	[illegible]	[illegible]nchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	[illegible]	[illegible]	(end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN	(cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM	(end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB	(substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC	(escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS	(file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS	(group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS	(record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US	(unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

What's Missing?

Binary Encoding – Characters/Text

- ASCII Encoding (www.asciitable.com)
  - *American* Standard Code for Information Interchange
- Created in 1963
  - Memory was expensive, 32KB in brand new machines
  - *Economic incentive* to use fewer bits for encoding
- **Design Goals:**
  - Represent everything on an *American* typewriter as *efficiently* as possible
  - Organize similar characters together
    - Numbers, uppercase, lowercase, then other stuff

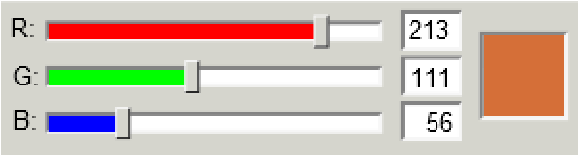
Binary Encoding – Unicode & Emoji

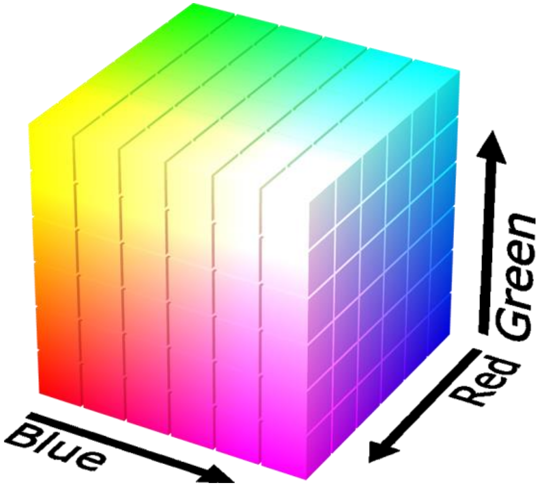
- Unicode Standard is managed by the Unicode Consortium
  - "Universal language" that uses 1-4 bytes to represent a much larger range of characters/languages, including emoji
  - Adds new emojis every year, though adoption often lags: ⍰
    - https://emojipedia.org/new/

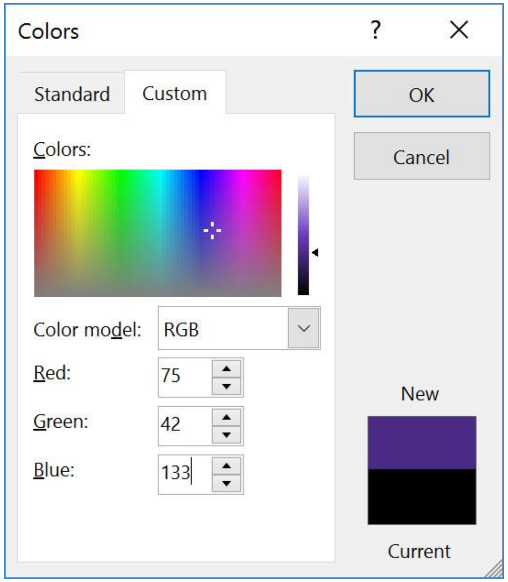
- Emojipedia demo: http://www.emojipedia.org
  - Desktop Computer: 
  - Code points: U+1F5A5, U+FE0F
  - Display: 

Binary Encoding – Colors

- RGB – Red, Green, Blue
  - Additive color model (light): byte (8 bits) for each color
  - Commonly seen in hex (in HTML, photo editing, etc.)
  - Examples: **Blue**→0x0000FF, **Gold**→0xFFD700, **White**→0xFFFFFF, **Deep Pink**→0xFF1493







Binary Encoding – Files and Programs

- At the lowest level, all digital data is stored as bits!
- Layers of abstraction keep everything comprehensible
  - Data/files are groups of bits interpreted by program
  - Program is actually groups of bits being interpreted by your CPU
- Computer Memory Demo (if time)
  - Linux tool: `xxd`

Summary

- Humans think about numbers in decimal; computers think about numbers in binary
  - Base conversion to go between them
  - Hexadecimal is more human-readable than binary
- All information on a computer is binary
- Binary encoding can represent *anything*!
  - Computer/program needs to know how to interpret the bits
  - Encodings aren’t “neutral”; priorities are baked in