The Hardware/Software Interface

CSE 351, Summer 2022

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http://xkcd.com/676/

Lecture Outline

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

Introductions: Course Staff

- Instructor: Kyrie Dowling
  - Just graduated with my BS in Computer Engineering
  - Starting a Master's program in the Fall at UPenn
  - Long time TA, first time instructor!
- 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!

- ~50 students registered!

- CSE, Math, Pre Sci, Pre Maj, ENGRUD, and many more!
  - Most of you will find almost everything in the course new
  - Many of you are new to CSE and/or UW!

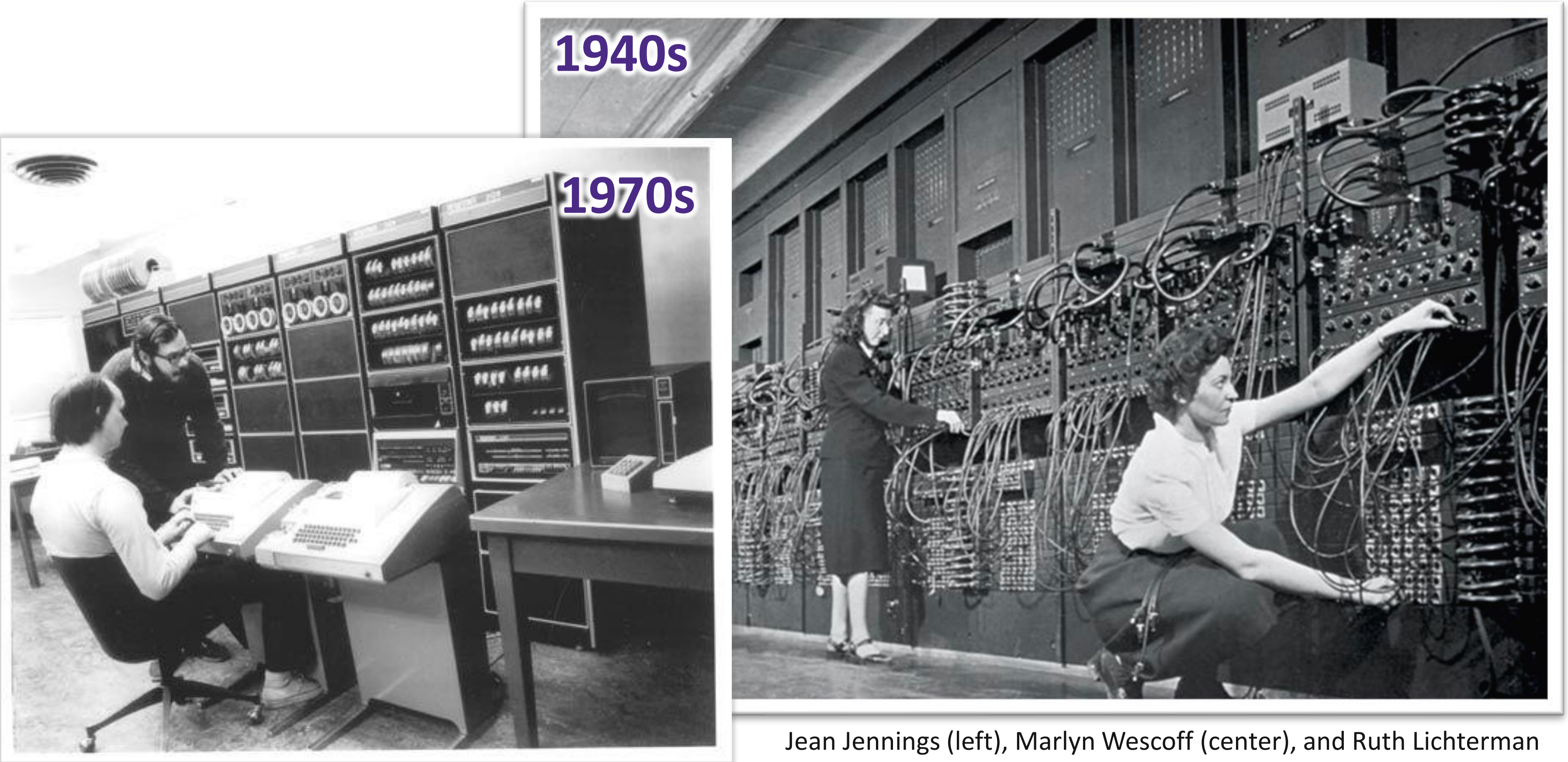
- Get to know each other! Help each other out!
  - Science says that learning happens best in groups
  - Working well with others is a valuable life skill
  - Diversity of perspectives expands your horizons
  - Take advantage of group work, where permissible, to *learn*, not just get a grade

Welcome to CSE 351!

- See the key abstractions "under the hood" to describe "what really happens" when a program runs
  - How is it that "everything is 1s and 0s"?
  - Where does all the data get stored and how do you find it?
  - How can more than one program run at once?
  - How does your source code become something that your computer understands?
- An *introduction* that will:
  - Profoundly change/augment your view of computers and programs
  - Connect your source code down to the hardware
  - Leave you impressed that computers ever work
  - Help you understand the values that have informed the history of computing, and how you can think critically about them

HW/SW Interface: Historical Perspective

- Hardware started out quite primitive



https://s-media-cache-ak0.pinimg.com/564x/91/37/23/91372375e2e6517f8af128aab655e3b4.jpg

Jean Jennings (left), Marlyn Wescoff (center), and Ruth Lichterman program ENIAC at the University of Pennsylvania, circa 1946.
Photo: Corbis
http://fortune.com/2014/09/18/walter-isaacson-the-women-of-eniac/

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)

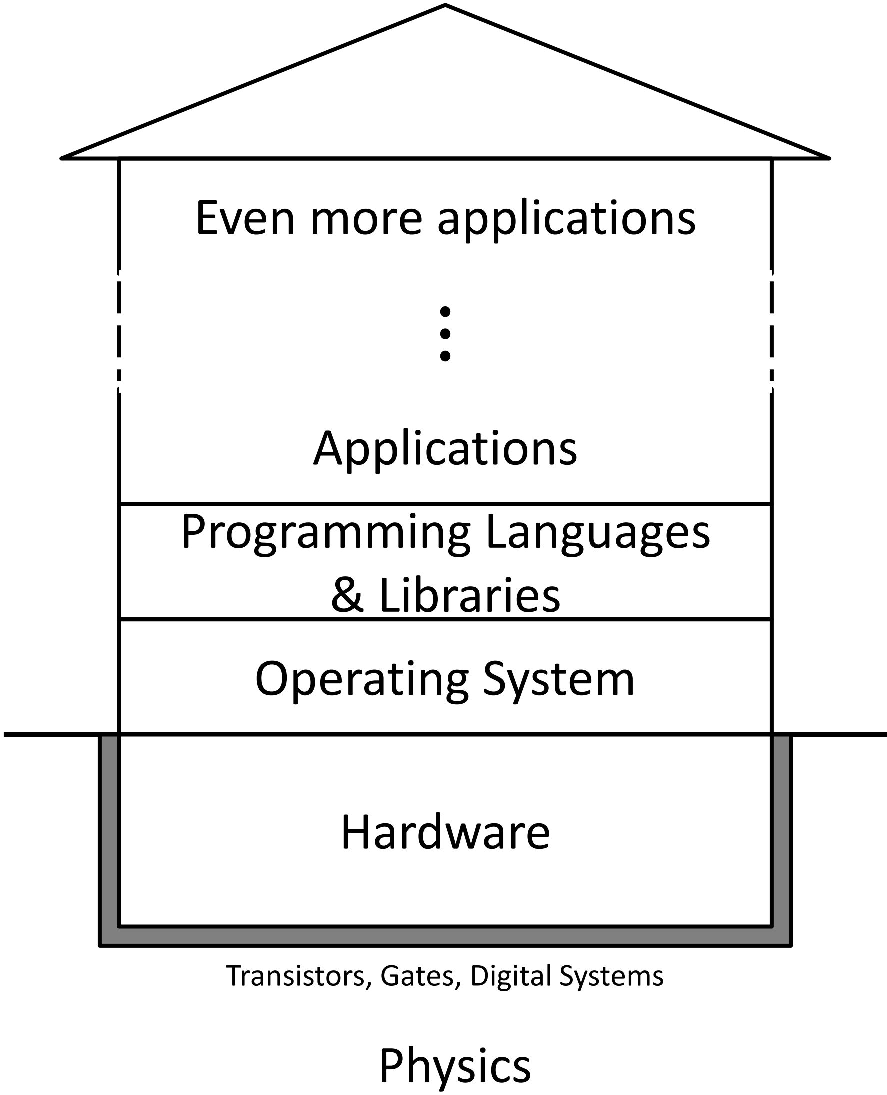
HW/SW interface

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

Course Topics Poll

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

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Bookmarks

- Website: https://courses.cs.washington.edu/courses/cse351/22su
  - Schedule, policies, materials, videos, assignment specs, etc.
- Ed Course: https://edstem.org/us/courses/23206
  - Discussion: announcements, ask and answer questions
  - Lessons: readings, lecture questions, homework
  - Resources: links to other tools and information

- Linked from website and Ed
  - Canvas: gradebook, Zoom links
  - Gradescope: lab submissions
  - Panopto: lecture recordings

Extenuating Circumstances

- Students (and staff) still 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

Inclusiveness

- It is very important to us that you have a positive experience in CSE 351 this quarter.
- If at any point you are made to feel uncomfortable, disrespected, or excluded by a staff member or student, please let us know.
  - You may talk with a staff member, email me directly, or send anonymous feedback (via the “Tools” menu on the website).

Course Components

- Lectures (25)
  - Introduce, review, and discuss content
  - Recorded and slides provided
- Sections (9)
  - Review, group work, and assignment help
  - No recordings, materials provided after
- Office Hours
  - Found under Events on course web page
- Pre-quarter and Mid-quarter Surveys (on Canvas)
  - Meant to check in and get to know you better

Course Components

- Pre-lecture readings
  - Found on Ed Lessons
- Labs (6)
  - In depth applications/investigations of course material
  - Specs on website, submitted via Gradescope
- Unit Portfolios (3)
  - Exam replacements focused on reflection and problem solving
- Can use up to 5 late days on labs (see syllabus for more details)

Grading

- **Pre-Lecture Readings:** ~5%
  - Can reveal solution after one attempt (completion)
- **Homework:** ~25% total
  - Unlimited submission attempts (autograded correctness)
- **Labs:** ~40% total
  - Last submission graded (correctness)
  - Can be done with a partner
- **Unit Portfolios:** ~25%
  - Three total; individual; more details coming soon
- **Participation:** ~5%

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!
    - In Zoom: TAs and I will monitor chat
    - In-person: 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

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
  - Course Policies due Friday (6/24)
  - Pre-Course Survey and due Fri (6/24)
  - Pre-lecture readings due before each lecture – 10 am
    - Optional Computer Systems reading given on course calendar
  - Binary Homework & Lab 0 due next Monday (6/27)

CSE Linux Environment

- Specific Operating System (OS) needed for labs
- Virtual Machine
- Secure Shell (ssh) Connection
    - Can connect to a remote machine from your locale machine
    - attu: machines CSE students can access (csenetid login)
    - cancun: machines non-CSE students can access (uwnetid login)
- If you have an M1 Macbook you'll have to connect to attu or cancun!

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- **Binary and Numerical Representation**

Reading Review

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

- Questions from the reading?

Review Questions

$16^0=1$

$16^1=16$

$16^2=256$

$108/16=6.\dots$

$108-16\cdot 6=12$

$d\times b^i$

- What is the *decimal value* of the numeral 107_8? $1\cdot 8^2+0\cdot 8^1+7\cdot 8^0=$

  $64+0+7=71$

  A. 71

  B. 87

  C. 107

  D. 568

- What is the decimal number 108 in hex?

  $\overset{2}{0}\overset{1}{6}\overset{0}{C}$

  0x0 6 C

  A. 0x6C

  B. 0xA8

  C. 0x108

  D. 0x612

- Represent 0b100/1101/1010/1101 in hex.

  4 D A D

  0x4DAD

- Represent 0x3C9 in binary.

  0b~~00~~11 1100 1001

Base Comparison

- Why does all 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 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 (nybble?)
- A group of 8 bits (2 hex digits) is called a byte
  - 1 bit → 2 things, 1 nibble → 16 things, 1 byte → 256 things

So, What Does It Mean?

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

- Consider the hex sequence 0x4E6F21
  - Common interpretations include:
    - The decimal number 5,140,257
    - The real number 7.203034 × 10^{-39}
    - The characters “No!”
    - The background color of this slide

- It is up to the program/programmer (you!) 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	144	d	d
5	5	005	ENQ	(enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK	(acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL	(bell)	39	27	047	'	'	71	47	107	G	G	103	[illegible]	147	g	g
8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	H	[illegible]	104	[illegible]	150	h	h
9	9	011	TAB	(horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	[illegible]	[illegible]	i	i
10	A	012	LF	(NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	[illegible]	106	[illegible]	152	j	j
11	B	013	VT	(vertical tab)	43	2B	053	+	[illegible]	[illegible]	4B	113	K	[illegible]	107	6B	153	k	k
12	C	014	FF	(NP form feed, new page)	44	2C	054	,	[illegible]	76	[illegible]	114	L	L	108	6C	154	l	l
13	D	015	CR	(carriage return)	45	2D	055	-	-	77	[illegible]	115	M	M	109	6D	155	m	m
14	E	016	SO	(shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI	(shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE	(data link escape)	[illegible]	[illegible]	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1	(device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2	(device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3	(device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	[illegible]	(device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK	(negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN	(synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB	(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

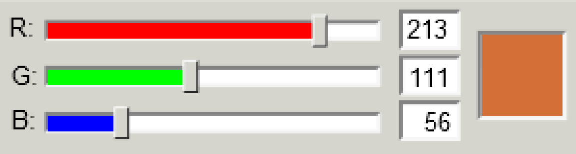
- **Design Goals:**
  - Represent everything on an *American* typewriter as *efficiently* as possible
  - Organize similar characters together
    - Numbers, uppercase, lowercase, then other stuff

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
    - Offer opportunities to be more inclusive of race and gender diversity
    - However, adoption often lags: 👸 and 🤴 added in 2015 and 2016, but non-gendered "person with crown" only added in 2021: ⍰
    - https://emojipedia.org/new/
- Emojipedia demo: http://www.emojipedia.org
  - Desktop Computer: 🖥
  - Code points: U+1F5A5, U+FE0F
  - Display:

Binary Encoding – Colors

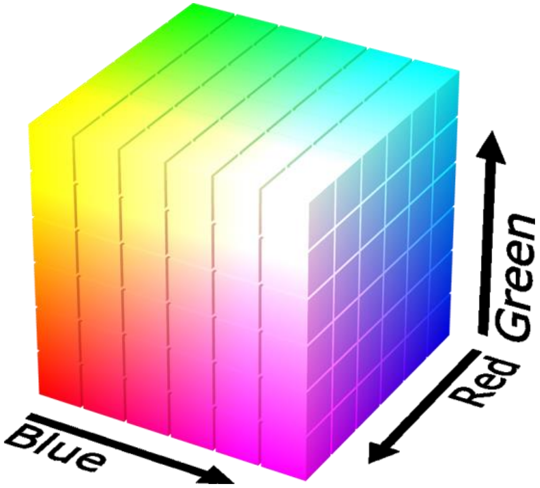
- RGB – Red, Green, Blue
  - Additive color model (light): byte (8 bits) for each color
  - Commonly seen in hex (in HTML, photo editing, etc.)
  - Examples: **Blue**→0x0000FF, **Gold**→0xFFD700, **White**→0xFFFFFF, **Deep Pink**→0xFF1493

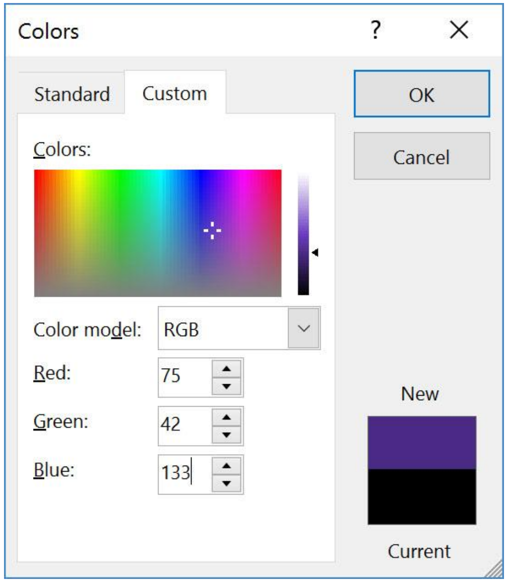


R: 213

G: 111

B: 56





Color model: RGB

Red: 75

Green: 42

Blue: 133

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 groups of bits being interpreted by your CPU

- Computer Memory Demo (if time)
  - From vim: `%!xxd`
  - From emacs: `M-x hexl-mode`

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