

# CS50's Understanding Technology

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## Hardware

by Spencer Tiberi

## Binary

- We use computers everyday
- Inside a computer are “0s and 1s”
  - Computers use the binary number system to represent info
    - How do computers represent info with just binary?
- Consider the decimal number (what we human typically use) 123
  - The rightmost column is the 1s column
  - The middle, the 10s
  - The leftmost, the 100s

100	10	1
1	2	3

- Thus we have  $100 \times 1 + 10 \times 2 + 1 \times 3 = 100 + 20 + 3 = 123$
- Inside a computer, the binary 000 would represent 0, just like in our human world!
  - However, in this case we are dealing with binary so:
    - The right most column is the 1s place
    - The middle, the 2s
    - The leftmost, the 4s

4	2	1
0	0	0

- In the human world (decimal) we use powers of 10 for place values
  - $10^0 = 1, 10^1 = 10, 10^2 = 100, 10^3 = 1000$ , etc.
- In the computer world (binary) we use powers of 2 for place values
  - $2^0 = 1, 2^1 = 2, 2^2 = 4, 2^3 = 8$ , etc.
- The difference between decimal numbers and binary numbers is changing the base
- For the binary number 000, we have  $4 \times 0 + 2 \times 0 + 1 \times 0 = 0 + 0 + 0 = 0!$
- Consider the binary number 001:

4	2	1
0	0	0

- We have  $4 \times 0 + 2 \times 0 + 1 \times 1 = 0 + 0 + 1 = 1$
- How do we represent the decimal number 2 in binary?
  - We don't need a 4, be we need a 2, and also no 1

4	2	1
0	1	0

- This gives us  $4 \times 0 + 2 \times 1 + 1 \times 0 = 0 + 2 + 0 = 2$
- Likewise, the number 3 would be:

4	2	1
0	1	1

- As we need a 2 and a 1
- Thus,  $4 \times 0 + 2 \times 1 + 1 \times 1 = 0 + 2 + 1 = 3$
- Similarly, 4 would be:

4	2	1
1	0	0

- What about 7?

4	2	1
1	1	1

- Which yields  $4 \times 1 + 2 \times 1 + 1 \times 1 = 4 + 2 + 1 = 7$

- What about 8?

- We can't count to 8 without another bit (binary digit)
  - We run into this in the real world too if we need a four-digit number vs a 3-digit number
    - Start with the 1s, 10s, 100s place and add the 1000s
    - Here we'll add the next power of 2, 8

8	4	2	1
1	0	0	0

- $8 \times 1 + 4 \times 0 + 2 \times 0 + 1 \times 0 = 8$

- Even though computers only use binary, they can count as high as humans can!

- They do it with a smaller vocabulary, just 1 and 0.
  - This is because it's easier to represent two states in the physical world
    - If you think of one of these bits as being a light bulb:
      - 0 is off
      - 1 is on
    - Light bulbs just need electricity to turn on or off
    - Electricity is sufficient to turn a switch on or off
      - Inside a computer exists these switches called transistors
        - Modern computers have billions!
        - Turned off represents 0
        - Turned on represents 1

- Using these transistors we can store values, store data, compute, and do everything we can with computers
- David demonstrates how transistors work using light bulbs
- So far all that we can represent is numbers

- A decision needs to be made on what pattern of 1s and 0s to represent letters, words, and paragraphs
- All computers can store 0s and 1s
- To represent letters, we need a mapping of 0s and 1s to characters
  - ASCII (American Standard Code for Information Interchange) does this

0	<u>NUL</u>	16	<u>DLE</u>	32	<u>SP</u>	48	0	64	@	80	P	96	'	112	p
1	<u>SOH</u>	17	<u>DC1</u>	33	!	49	1	65	A	81	Q	97	a	113	q
2	<u>STX</u>	18	<u>DC2</u>	34	"	50	2	66	B	82	R	98	b	114	r
3	<u>ETX</u>	19	<u>DC3</u>	35	#	51	3	67	C	83	S	99	c	115	s
4	<u>EOT</u>	20	<u>DC4</u>	36	\$	52	4	68	D	84	T	100	d	116	t
5	<u>ENQ</u>	21	<u>NAK</u>	37	%	53	5	69	E	85	U	101	e	117	u
6	<u>ACK</u>	22	<u>SYN</u>	38	&	54	6	70	F	86	V	102	f	118	v
7	<u>BEL</u>	23	<u>ETB</u>	39	'	55	7	71	G	87	W	103	g	119	w
8	<u>BS</u>	24	<u>CAN</u>	40	(	56	8	72	H	88	X	104	h	120	x
9	<u>HT</u>	25	<u>EM</u>	41	)	57	9	73	I	89	Y	105	i	121	y
10	<u>LF</u>	26	<u>SUB</u>	42	*	58	:	74	J	90	Z	106	j	122	z
11	<u>VT</u>	27	<u>ESC</u>	43	+	59	;	75	K	91	[	107	k	123	{
12	<u>FF</u>	28	<u>FS</u>	44	,	60	<	76	L	92	\	108	l	124	
13	<u>CR</u>	29	<u>GS</u>	45	-	61	=	77	M	93	]	109	m	125	}
14	<u>SO</u>	30	<u>RS</u>	46	.	62	>	78	N	94	^	110	n	126	~
15	<u>SI</u>	31	<u>US</u>	47	/	63	?	79	O	95	_	111	o	127	<u>DEL</u>

- 65 -> A, 66 -> B, 67 -> C, etc.
- 97 -> a, 98 -> b, 99 -> c, etc.
- ASCII also has mapping for punctuation symbols
- Programs like notepad, textedit, and MicroSoft Word decide whether to display patterns of bits as letters or words
  - Computers only store 0s and 1s, but the programs interpret those bits in a certain way
    - For example, if MicroSoft word sees a pattern of bits representing the number 65, it will interpret that as "A"
- ASCII is limited
  - Original ASCII is 7 bits, thus giving 128 characters
    - Extended ASCII is 8 bits, yielding 256 characters
  - Many symbols are not represented
- UNICODE is a bigger set of characters that includes written languages other than English and even emoji! 😊
  - All are still represented by a pattern of bits
- Consider this pattern of bits: 01001000 01001001
  - 16 bits or 2 bytes (1 byte = 8 bits)

128	64	32	16	8	4	2	1		128	64	32	16	8	4
0	1	0	0	1	0	0	0		0	1	0	0	1	0

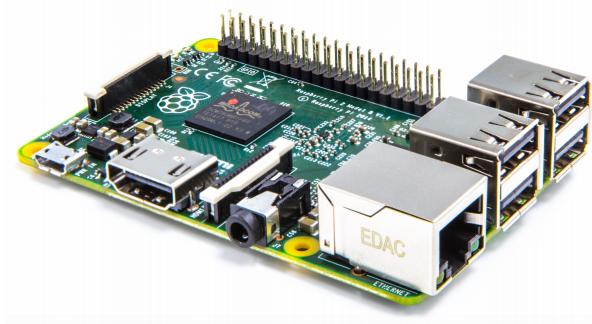
<b>1 x 64 + 1 x 8</b>	<b>1 x 64 + 1 x 8 + 1 x 1</b>
72	73
H	I

- Using ASCII we get the word “HI”

## CPU

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- If you have heard that your computer has “Intel Inside,” it has an Intel processor in it
 A photograph of an Intel Core i7 processor. The processor is a silver square with a gold-colored metal base. The Intel logo and "Core™ i7" are printed on the top surface. The gold base has a grid of pins for connecting to a motherboard.
- The backside of the processor has pins that connect into the motherboard
  - The motherboard is a circuit board made of silicon
- The CPU is the brain of the computer
  - Does all the thinking
  - Performs math in numbers fed to it
  - Helps display numbers on a screen
  - Adds or deletes numbers
- CPUs now can have multiple cores
  - Cores are the devices inside the CPU that can perform mathematical operations, load info from memory, save info to memory, etc.
  - The more cores, the more tasks a CPU can do at once
- CPUs now also support hyper-threading
  - Where a single core will present itself as multiple cores to a computer's operating system
- Systems on a Chip (SoaC) are when a CPU and more are all interconnected at once rather than attached to a motherboard
  - Popular in phones, tablets, and game consoles
  - Raspberry Pi

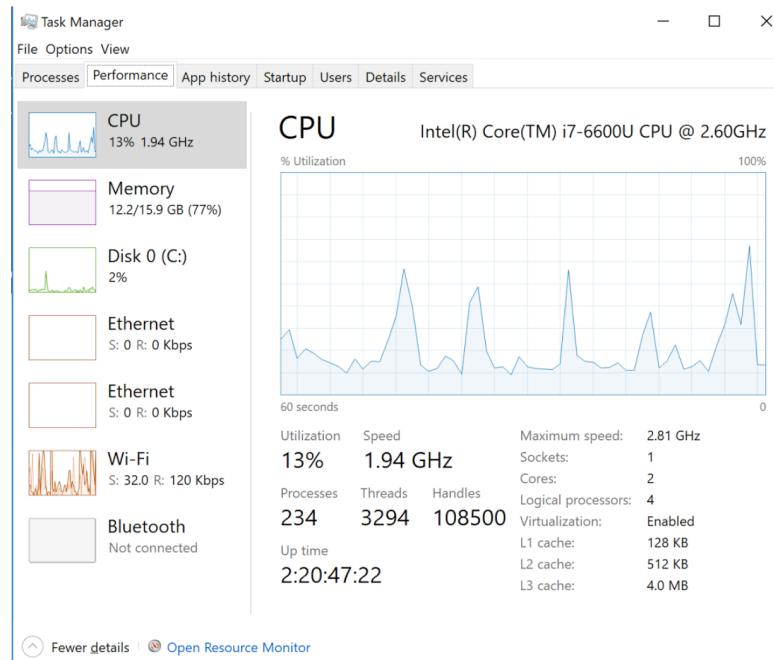


## RAM (Random Access Memory)

- Circuit board with chips that slides into a slot on the motherboard



- The chips store data
  - Only stores data when the power is on
  - Files and programs are loaded onto these chips when ran
  - Fast memory
- You can check your RAM and other specs:
  - Windows Task Manager



- CPU chart shows when peak usage occurs
- GHz is the number of operations a CPU can perform per second (in billions)
  - 1.94 GHz = 1.94 billion operations per second
- Logical processors in this case is 4, which means both cores support hyper-threading

- Each core will do two things at once as if 4 cores exist
- Mac System Profiler

#### Hardware Overview:

Model Name:	MacBook Pro
Model Identifier:	MacBookPro12,1
Processor Name:	Intel Core i7
Processor Speed:	3.1 GHz
Number of Processors:	1
Total Number of Cores:	2
L2 Cache (per Core):	256 KB
L3 Cache:	4 MB
Memory:	16 GB

## Hard Drives

- When you turn a computer off, you need a place to store data
  - A hard disk drive (HDD) stores this information



- RAM may store 1 GB, 2 GB, 4 GB, through 16 GB or so
- HDD stores 256 GB, 1024 GB (AKA terabyte or TB), 2 TB
- Inside a HDD, metal platters physically spin around



- Data is stored on these disks
- The reading heads move back and forth reading data from the device

- Uses tiny magnetic particles where north pole orientation represents 1 and south pole orientation represents 0
  - Power is only needed to read or change the data
    - Data is preserved when power is off
  - David shows a video of a HDD running in slowmo
- To store data in a hard drive, RAM sends data and instructions to the HDD
  - The hard drive translates that data into voltage fluctuations
    - Some signals spin the platters, others move the read/write heads
    - Pulses sent to the read/write head turn on a magnet which creates a field that changes the polarity of a tiny portion of the metal platter's surface
    - Power is sent in different directions as to change polarity
  - To read, the particles on the disk use their charge to move the read/write head.
  - Pieces of a file can be spread out around the platters
    - A special file keeps track of data's location
  - Anytime you have a physical device that moves over a period of time, things go wrong
    - Dropping a HDD can corrupt files
  - Platters spin slower than how fast electrons move

## Flash Memory

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- Solid state disk (SSD)



- Smaller (3.5 inch width for HDD vs 2.5 inch width for SSD)
  - Still fits where old HDDs are
  - No moving particles
  - Inside, it looks a lot like RAM



- Much faster than HDD
  - Programs/files load and save more quickly
- SSD theoretically don't last as long as HDD
  - Finite number of writes
- Hybrid Drives
  - Some GB of solid state memory and more GB or TB of HDD space
  - Stores as much of frequently-needed data on the SSD
  - Stores less frequently-needed data on HDD
- Flash memory also exists in the form of USB sticks
  - Might store 1 GB, 16 GB, or more
  - Portable
- External SSDs exist for more storage
  - Might store 256 GB or more
  - Can be used to share data with others without network usage
- Can also have external HDD

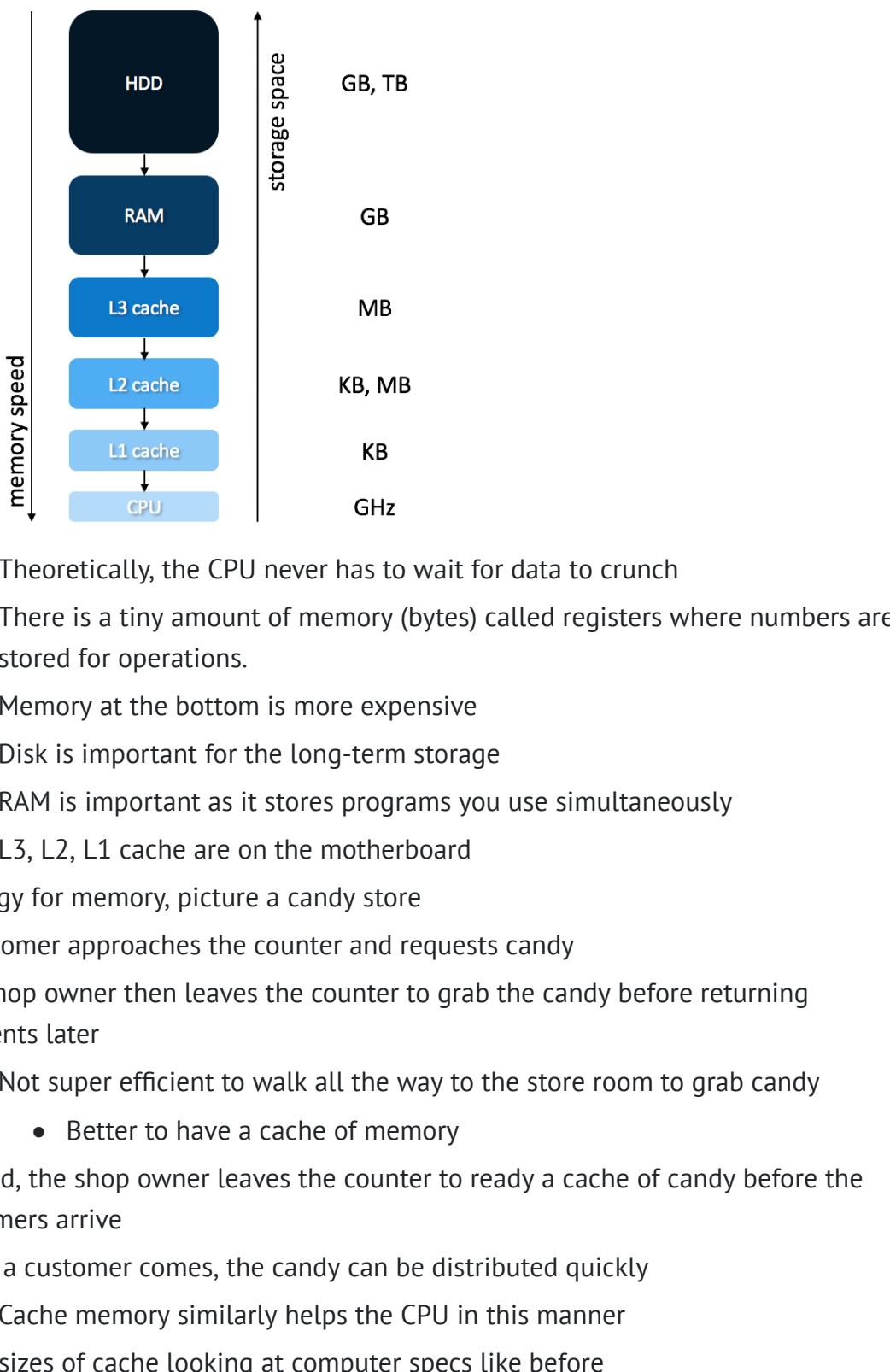
## Types of Memory and Funneling

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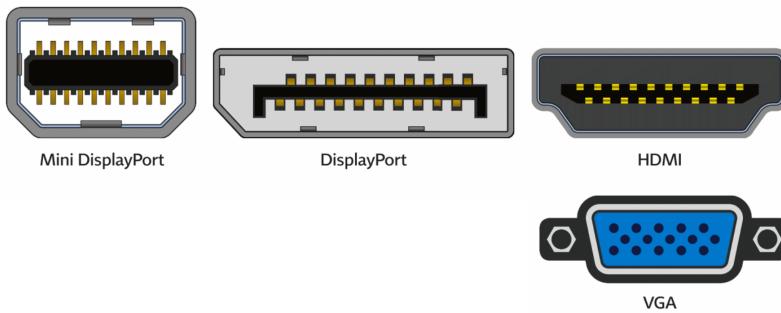
- There is a tradeoff between space, money, and speed of data transfer



- Data is pushed “down the funnel” to your CPU
  - From the hard drive, data first goes to the RAM

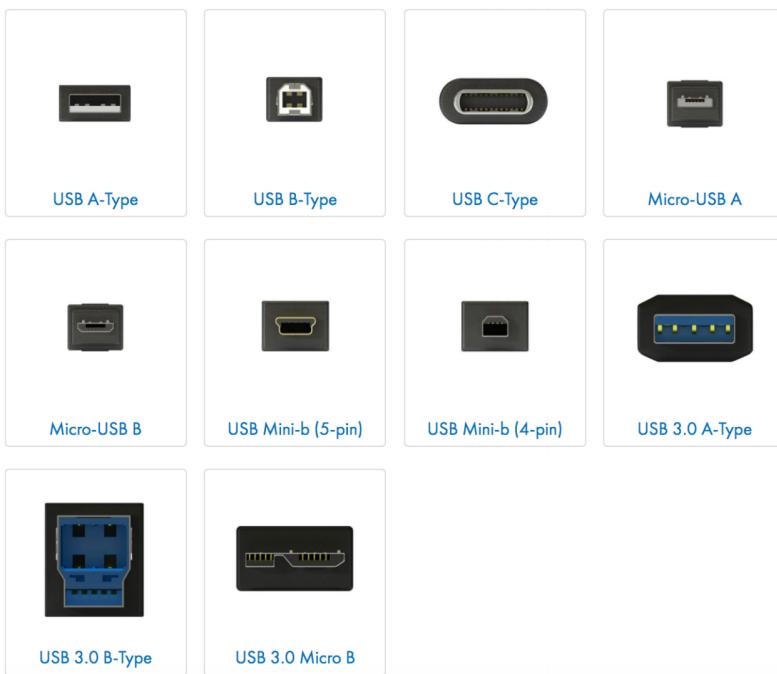


## Display Connectors



- These sockets all connect to monitors or displays
- Mini DisplayPort are used from monitors
- HDMI is not only on laptops and computers but also TVs
- VGA is older, but still commonly used on projectors

## USB (Universal Serial Bus)



- Can plug in a wide range of peripheral devices including printers, keyboards, mice, scanners, etc.
- USB-A is most common
- USB-B is often used for printers and scanners
- USB-C is newer and can be plugged in from different directions
- Other variants often exist for phones
- Older USB connections are slower when transferring data
  - Hard drives can connect via USB
    - Even if a hard drive is fast, if the USB is slow, the transfer of data will be slow

## Wireless

- Wifi is wireless internet
- Bluetooth allows devices such as wireless keyboards and headphones to connect to your computer
  - Limited range
    - This is ok as it is used for you to connect to your own device

## Operating System (OS)

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- Software that ensures all devices work and can intercommunicate
- MacOS and Windows are popular OS
- Can be installed by the user, but is typically done so by a manufacturer
  - Installed on HDD or SSD so that it exists persistently without power
- When you hit power on your computer, the OS is loaded into RAM
- Gives you the graphical interface that you see
- Knows how to:
  - Talk to your keyboard and mouse
  - Display info on the screen
  - Move things around in memory
- This is all thanks to device drivers installed with the OS
  - Special software designed to talk to certain model of printer, camera, scanner, etc.
- When an OS doesn't recognize a device, perhaps because it's too new, you can download new device drivers from the device manufacturer
  - Teaches Window, MacOS, or Linux about that new hardware
  - Future-proofing structure
- It's this intersection of hardware and software that makes computers powerful!

## Looking Underneath the Hood

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- David and Colton Ogden look at the exterior of an old ThinkPad computer, examining ports
  - Power bricks convert power from the wall into safe amounts for the computer
- David and Colton examine the inside of an old window desktop, highlighting the motherboard, heatsink, RAM, Hard Drive, etc.
- David and Colton then look inside a HDD
  - Once exposed to air and dust, it's no longer reliable enough to use
- David and Colton then look at a motherboard examining all the ports on it

