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 x 1 + 10 x 2 + 1 x 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 x 0 + 2 x 0 + 1 x 0 = 0 + 0 + 0 = 0!
- Consider the binary number 001:

4	2	1
0	0	1

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

    - 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 weather 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 buts 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	2	1
0	1	0	0	1	0	0	0		0	1	0	0	1	0	0	1

1 x 64 + 1 x 8	1 x 64 + 1 x 8 + 1 x 1
72	73
H	I

  - Using ASCII we get the word "HI"

CPU

- If you have heard that your computer has "Intel Inside," it has an Intel processor in it

- 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 preform 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

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

- 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

- 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

        - Theoretically, the CPU never has to wait for data to crunch
        - There is a tiny amount of memory (bytes) called registers where numbers are stored for operations.
        - Memory at the bottom is more expensive
        - Disk is important for the long-term storage
        - RAM is important as it stores programs you use simultaneously
        - L3, L2, L1 cache are on the motherboard
- As an analogy for memory, picture a candy store
    - A customer approaches the counter and requests candy
    - The shop owner then leaves the counter to grab the candy before returning moments later
        - Not super efficient to walk all the way to the store room to grab candy
            - Better to have a cache of memory
    - Instead, the shop owner leaves the counter to ready a cache of candy before the customers arrive
    - When a customer comes, the candy can be distributed quickly
        - Cache memory similarly helps the CPU in this manner
- We can see sizes of cache looking at computer specs like before

Display Connectors

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

USB (Universal Serial Bus)

- Can plug in a whole range of peripheral devices including printers, keyboards, mice, scanners, etc.
- USB-A most common
- USB-B is often used for printers and scanners
- USB-C is newer and can be plugged in coming 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)

- 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 SDD 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 drives 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

- 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