



The Math of Digital...

As Understood by a Doofus

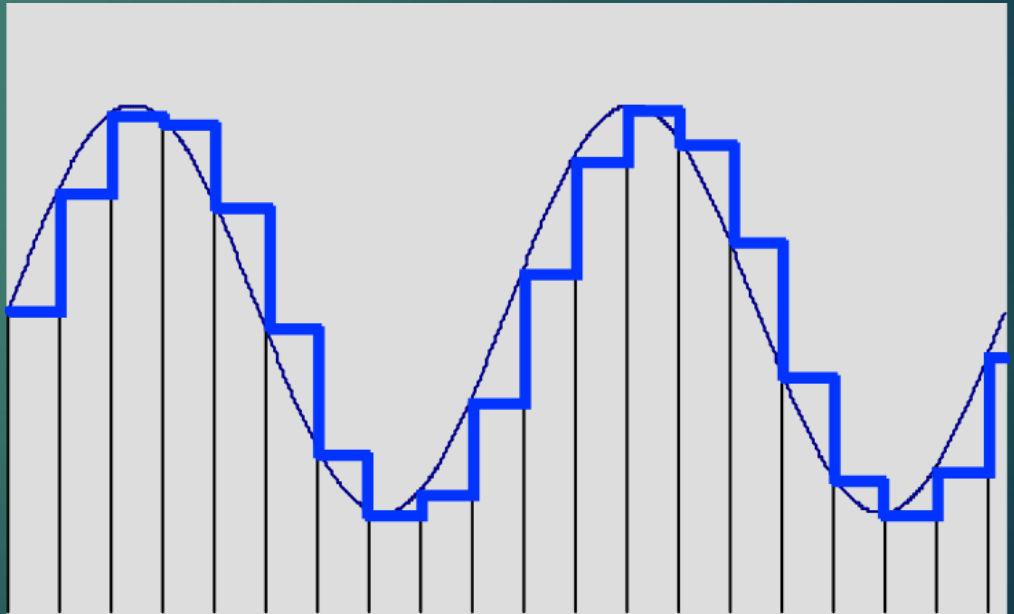
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INSTRUCTIONAL SUPPORT DOOFUS
“AV DOOFUS!”

Major caveat and disclaimer:

- ▶ I'm a doofus.
- ▶ I like math in picture form.

What do we really mean by digital?

- ▶ Approximation of the original analog signal or source
- ▶ Conveyed in a series of discrete “packets” of data
- ▶ Still sent somewhere using electrons



The world is continuous or “analog”

- ▶ Eyes and ears detect in analog
- ▶ Original Sources produce in analog – sound and light
- ▶ But it's also a bit digital or quantized...
- ▶ Atoms... explain quantized / discrete attributes
- ▶ Incandescent vs fluorescent
- ▶ Morse code
- ▶ Movie projectors

Something to think about

(courtesy of Jim Whitlock)

Going bobsledding. Mount a go-pro on helmet.

Have to choose:

4K vs 1080 pixels

24 vs 60 fps

And what about audio?

32kbps or 320kbps



Conversion from one to the other

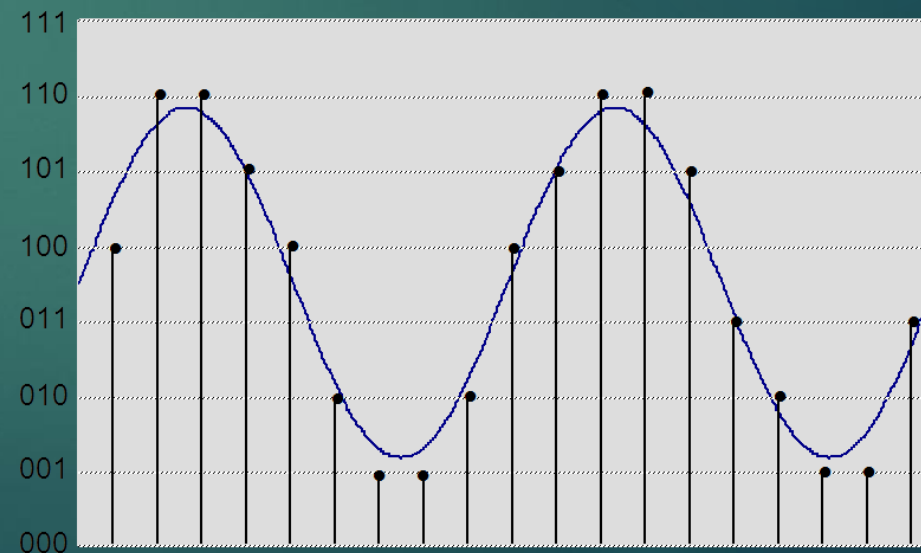
(A-D and D-A)

- ▶ Sensors, Circuitry, Code is used
- ▶ Companies make “Magic boxes” to do this
- ▶ And there are better and worse forms of each
- ▶ Nothing is perfect, so error is inevitable

BUT what are we trying to optimize?
What matters most in our application?
And can you hear it or see it?
Maximize quality vs Minimize cost...

Conversion from one to the other (continued)

- ▶ First we measure! (Sample rate, Bit depth, Frequency)
- ▶ Everything is measured at a snapshot in time
- ▶ The analog signal is “deconstructed” into packets of data
- ▶ Then everything is “reconstructed” afterward to reproduce the original
- ▶ Sounds simple, doesn't it?

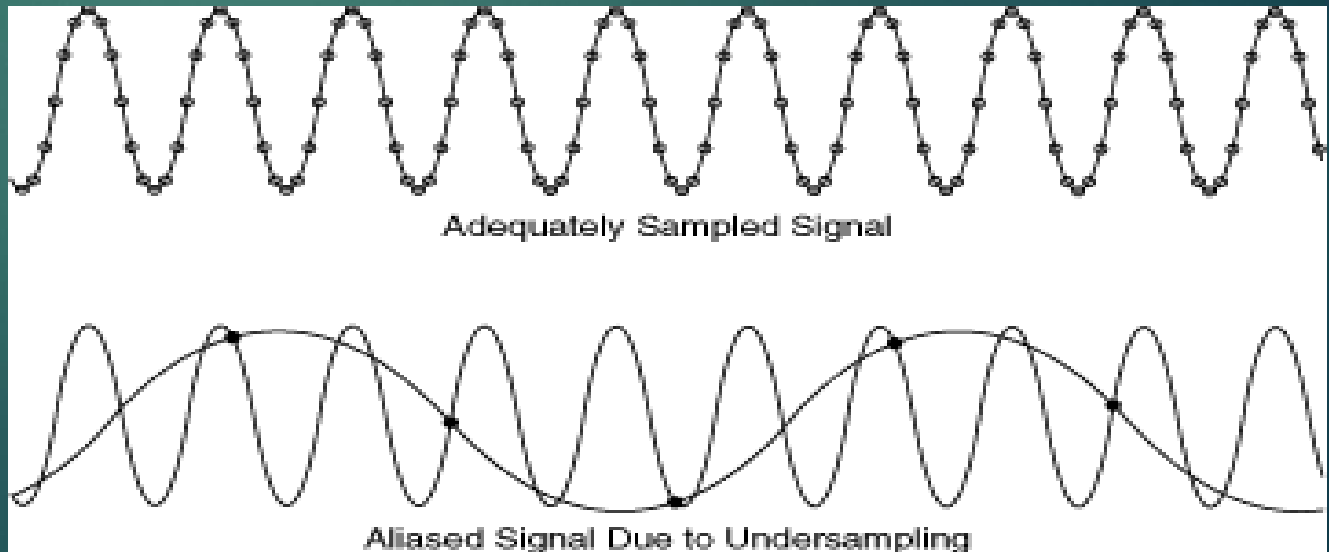


Sample Rate

- ▶ How many measurements per second
- ▶ Is more always better?
- ▶ What rate do you actually need?
- ▶ Nyquist theorem

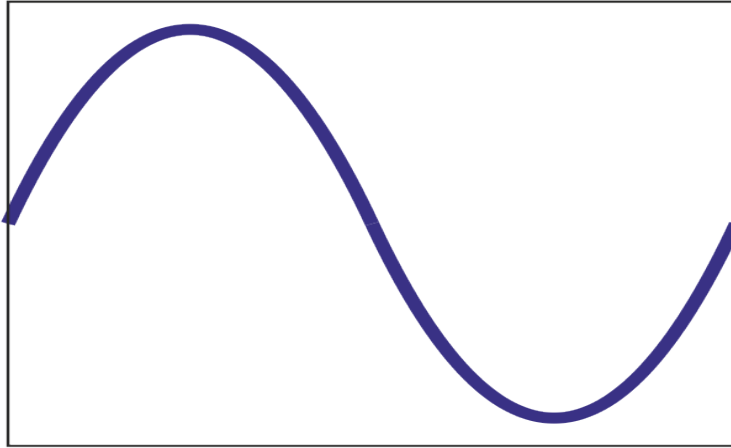
Need 2X the highest frequency to be measured

Aliasing is false frequency (wave) data from inadequate sampling

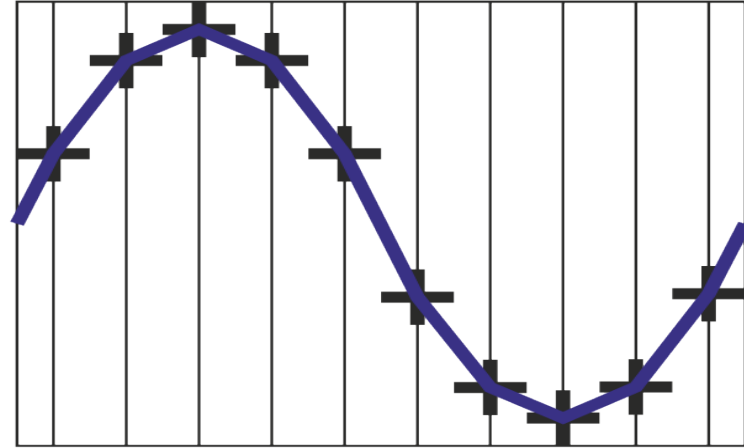


Sample Rate (also FPS)

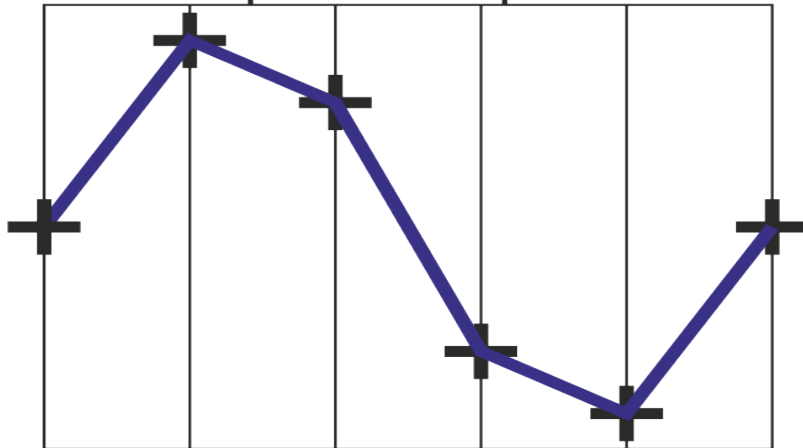
Original Waveform



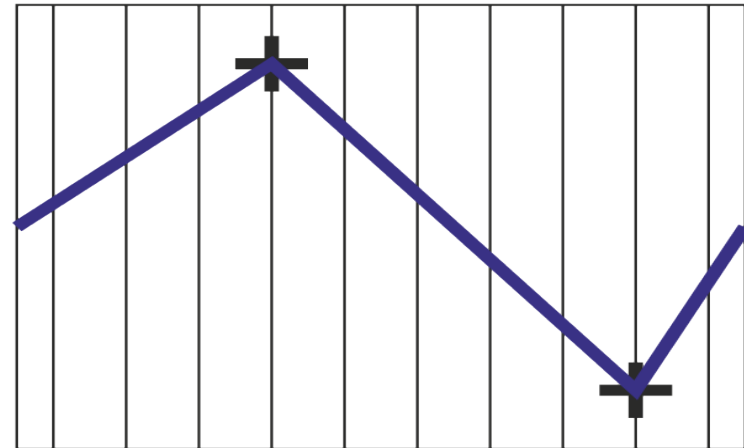
Sampled at 10 points



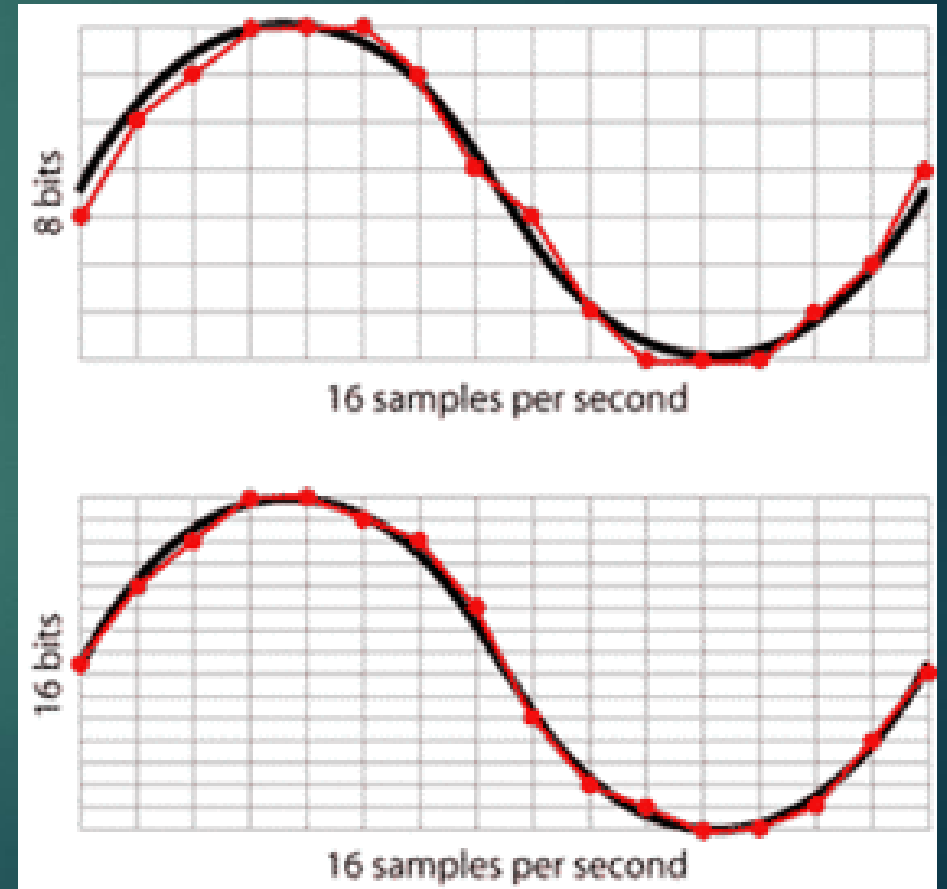
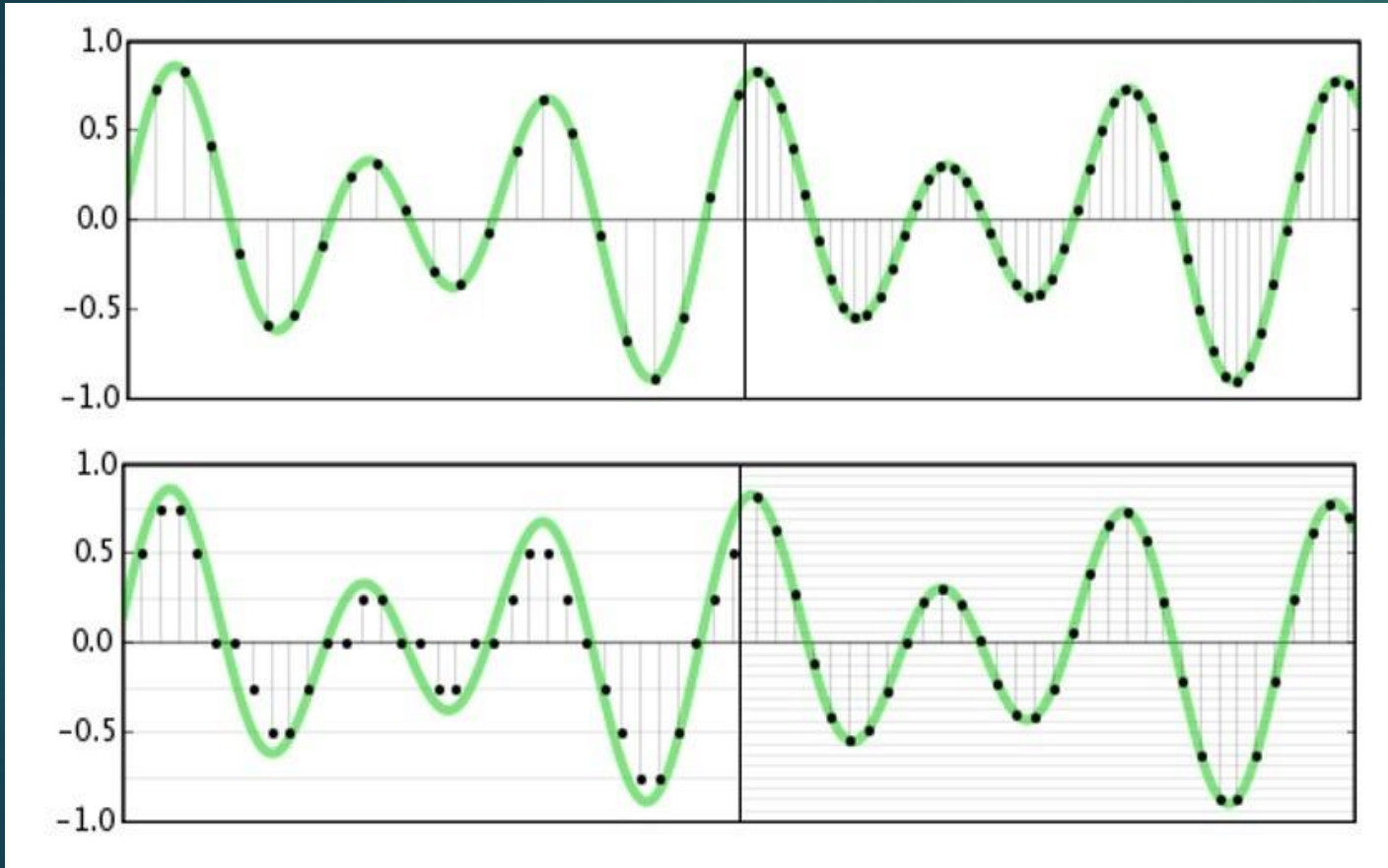
Sampled at 6 points



Sampled at 2 points



Sample Rate – measurements/sec



Bit Depth

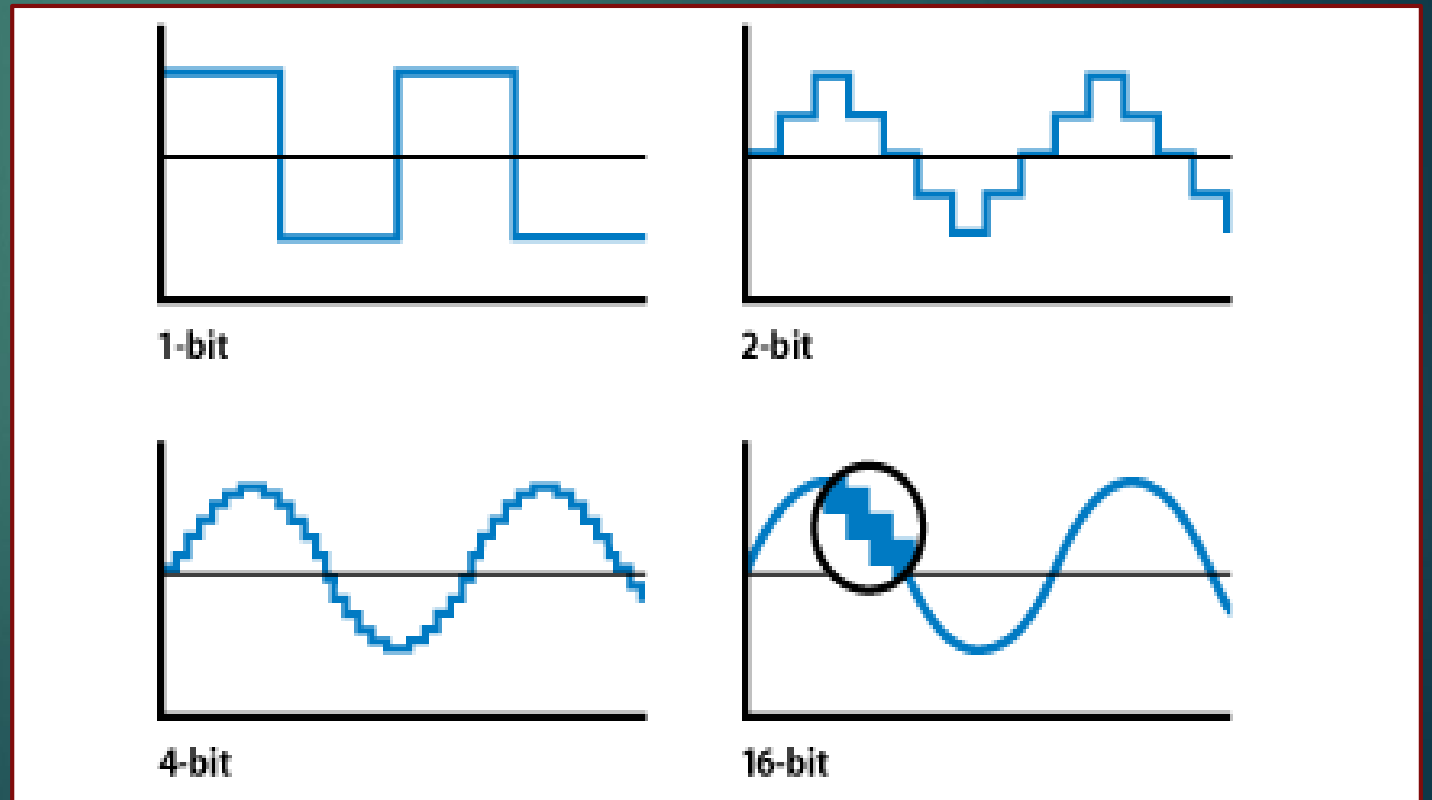
- ▶ How precise do we want the measurements to be?
- ▶ More bits means more precision (resolution)
- ▶ More bits means closer to accurate representation (maybe)
- ▶ More bits also means more data to send

Computers work in binary = ONE's and ZERO's.

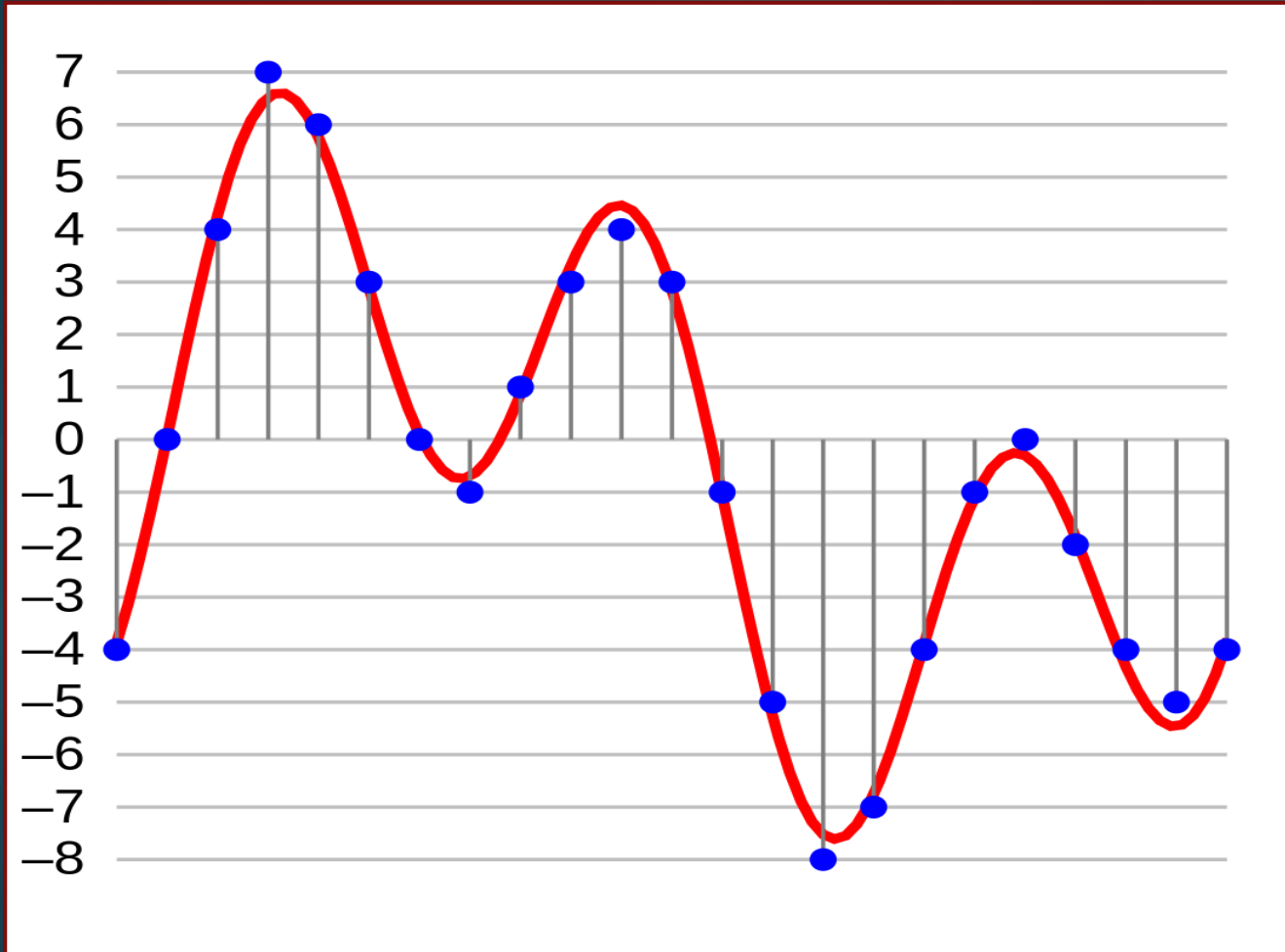
Presence or lack of voltage = transistor gate on or off.

Total number of combos = $2^{\text{bit depth}}$

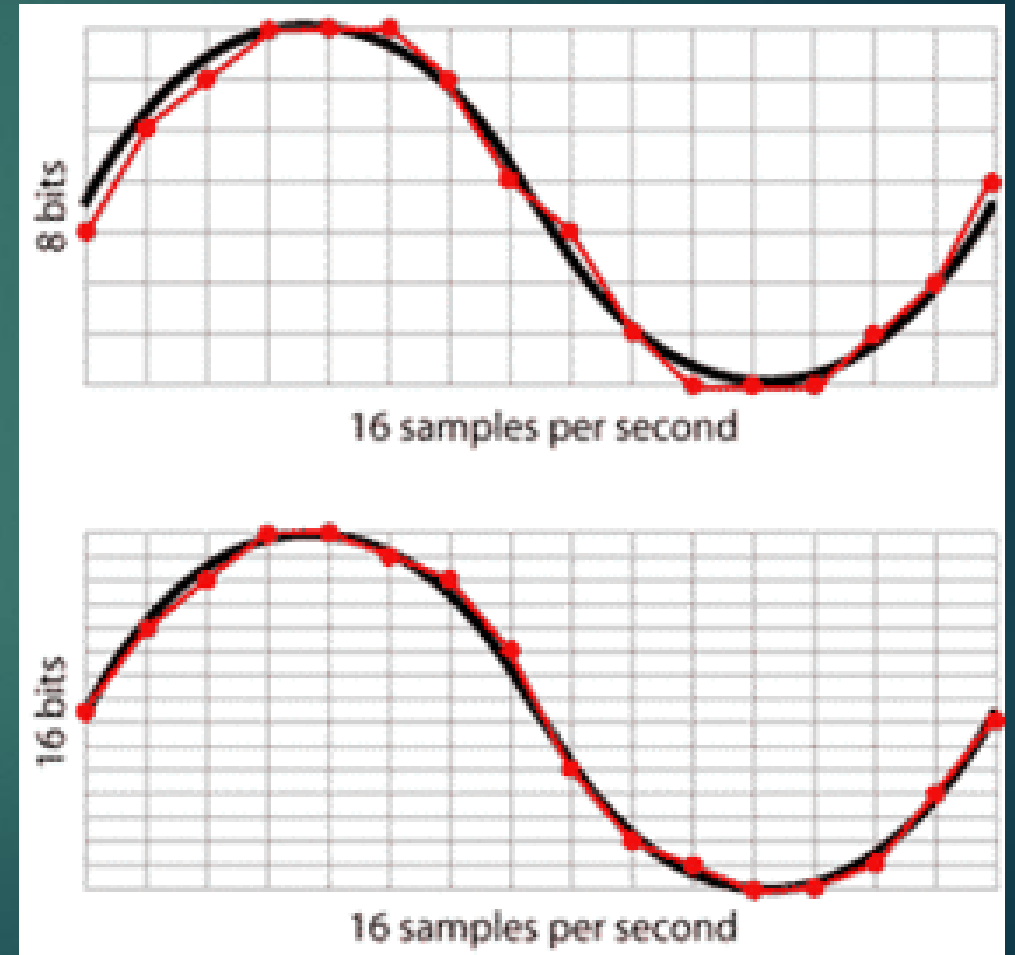
1011000100111110 = 16 bits



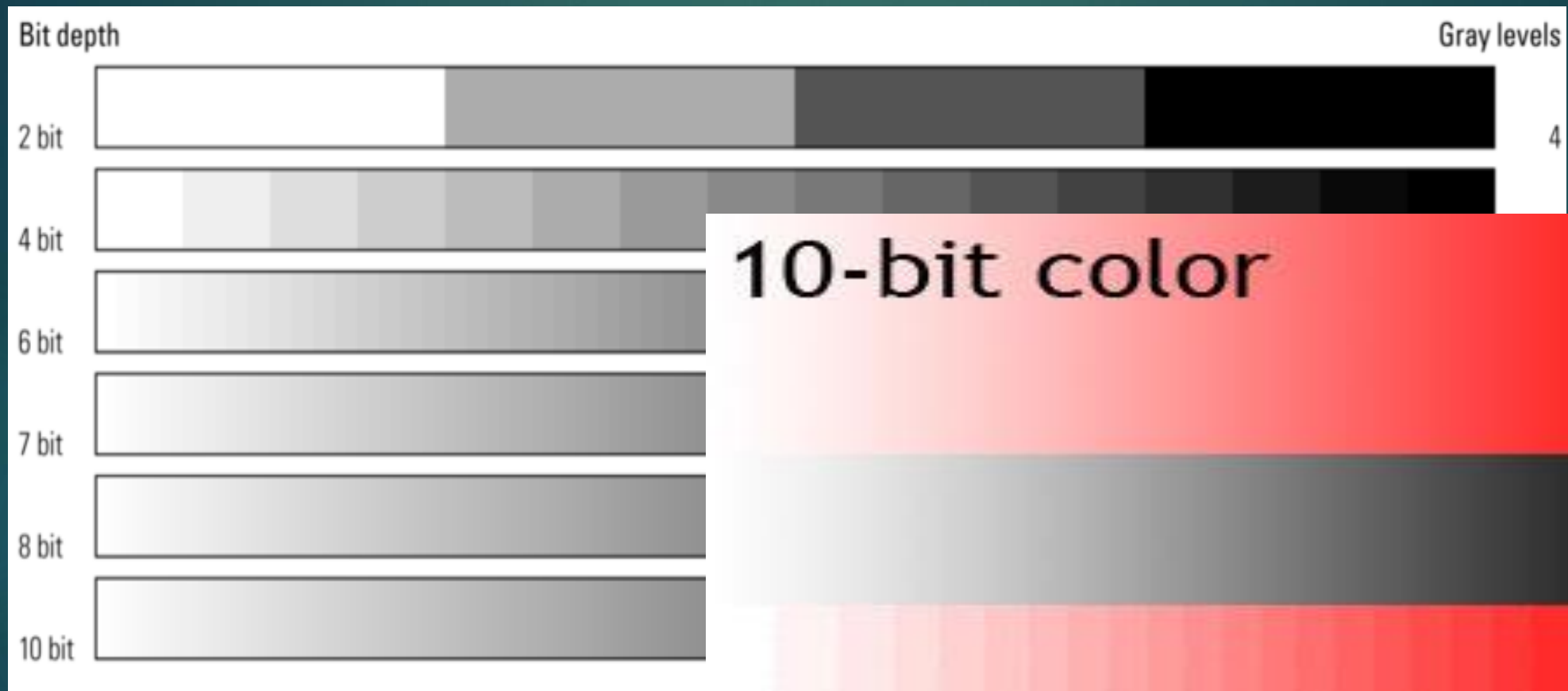
Bit Depth



How many bits here? FOUR!



Bit Depth

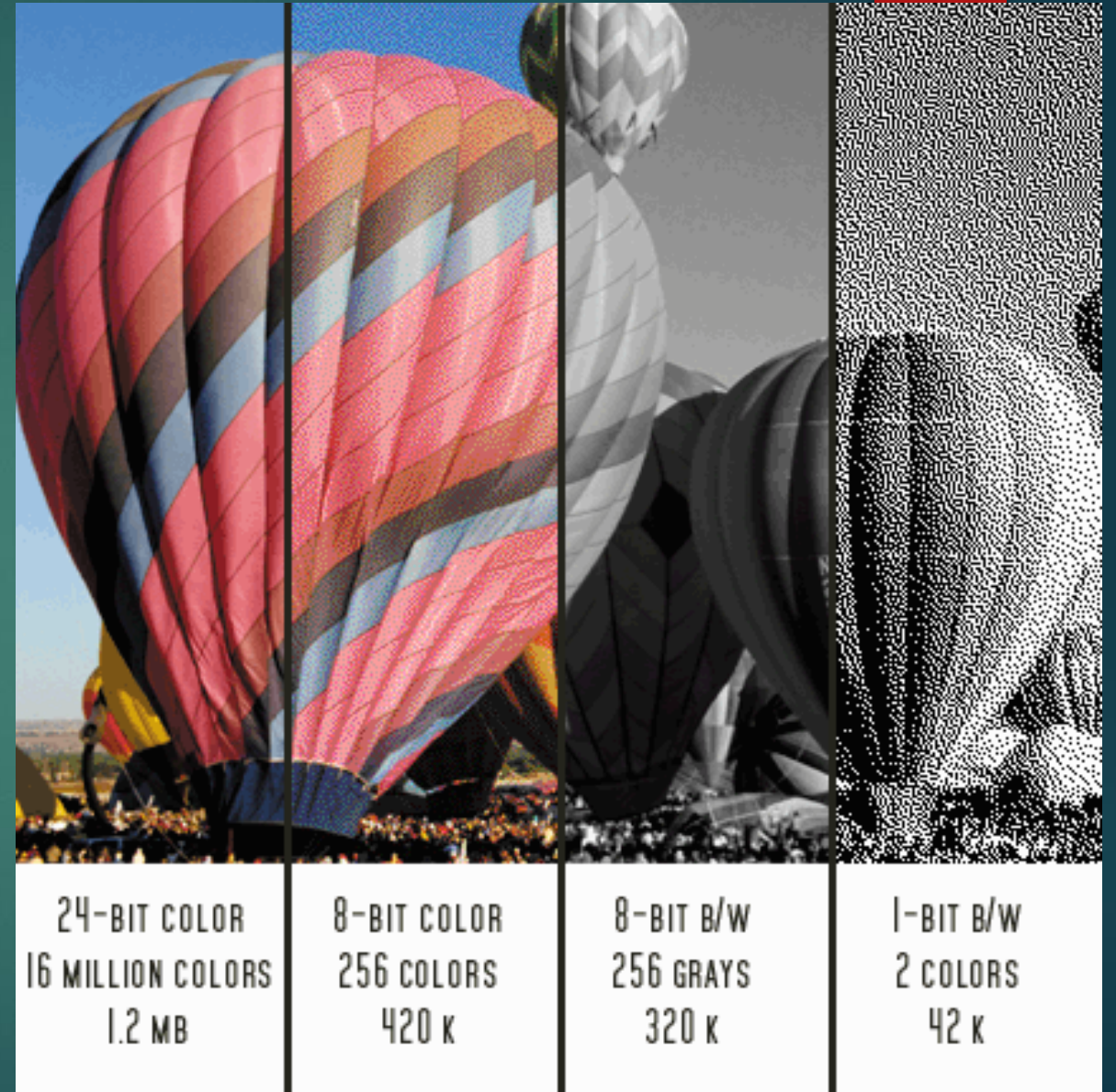


10-bit color

8-bit color

Bit Depth

	tones per channel per pixel	total possible tones
8 bit	256	16.78 million
10 bit	1,024	1.07 billion
12 bit	4,095	68.68 billion
14 bit	16,383	4.39 trillion
16 bit	65,532	281 trillion



Bit Rate and the Bandwidth Pipeline

- ▶ More samples per second at higher precision (resolution) will occupy more of the pipeline at any given time

BANDWIDTH IS FREQUENCY DEPENDENT

- ▶ Kbps or Mbps or Gbps of bandwidth

54K dialup 150M wireless 1000M wired

THANKFULLY IT CONTINUES TO INCREASE!

- ▶ Sample rate x Bit depth (# of bits) = bits per second

PCM audio 44100hz x 16bits = 705Kbps

Video 60fps x 16bits (in each pixel) = 960..... X 8000000 = 7.7Gbps!!

BUT EACH FRAME CONTAINS 8,000,000 PIXELS!

Bit Rate and the Bandwidth Pipeline

File Sizes For Stereo Digital Audio

Bit Depth	Sample Rate	Bit Rate	1 Stereo Minute	3 Minute Song
16	44,100	1.35 Mbit/sec	10.1 MB	30.3 MB
16	48,000	1.46 Mbit/sec	11.0 MB	33 MB
24	96,000	4.39 Mbit/sec	33.0 MB	99 MB
mp3	128 k/bit rate	0.13 Mbit/sec	0.94 MB	2.82 MB

Resolution & Frame Rate	H.264 Baseline Bitrate (kbps)	H.264 High Profile Bitrate (kbps)
1080p30	2048	1024
720p60	1512	832
720p30	1024	512
4CIF30	256	128
CIF30	128	64

Required bitrate for H.264 Baseline and H.264 High Profile at various video resolutions and frame rates

Discussion question

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Don't contact me

- ▶ Call Drew or Todd or Jim Whitlock

Just kidding! (of course you can contact me)

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- ▶ THANK YOU FOR JOINING!