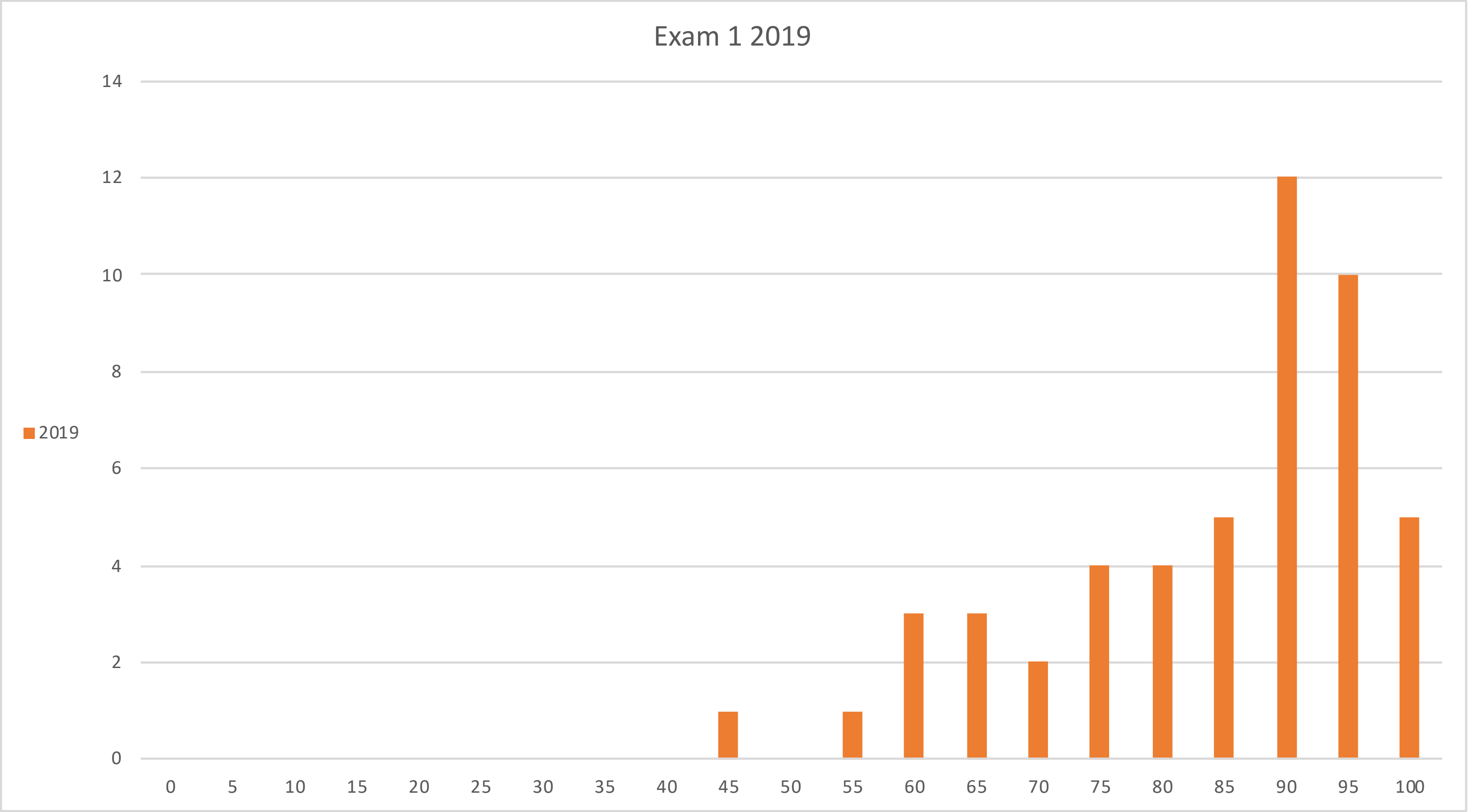
Data Representation: Images and Sound

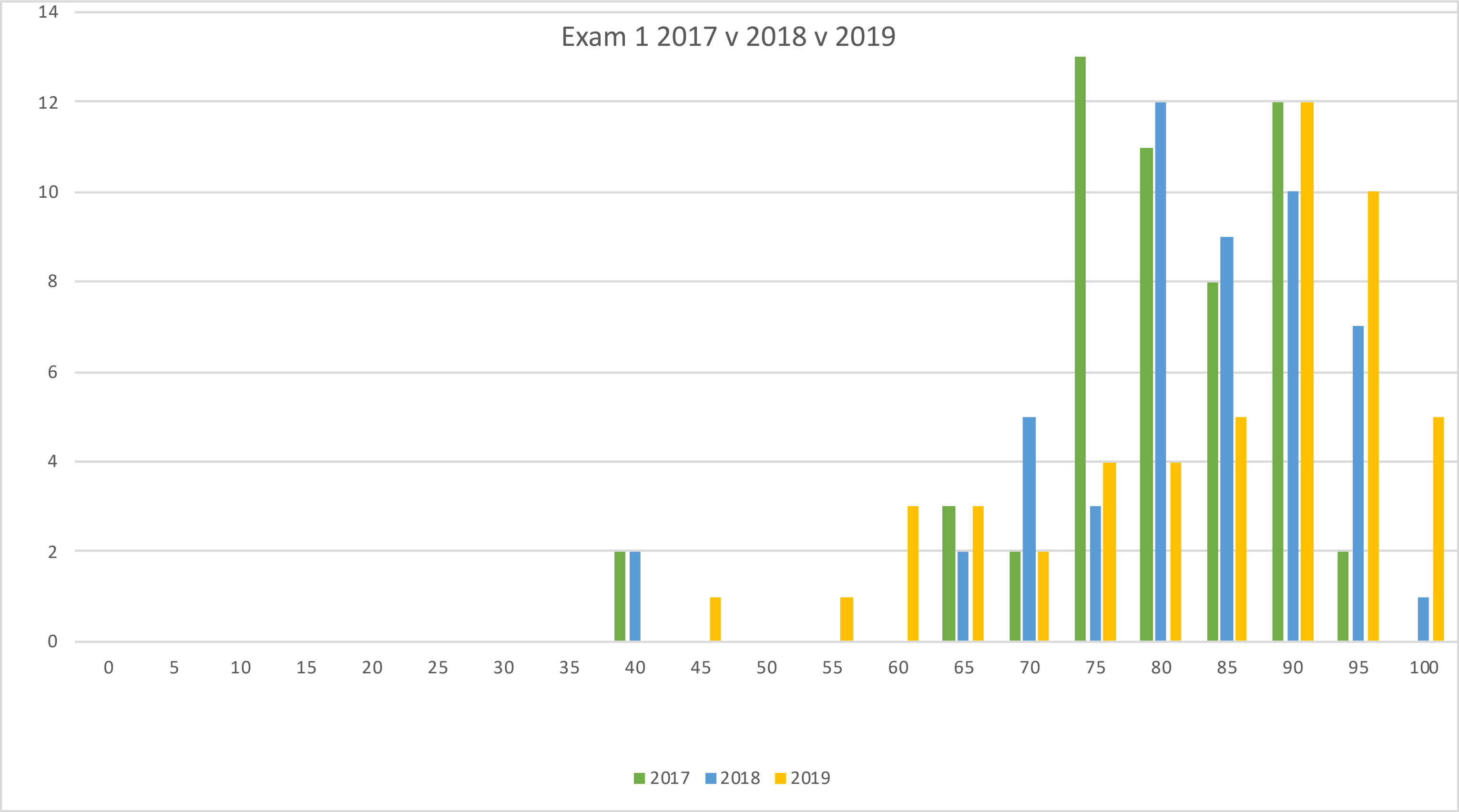
Announcements

- Lab Exam?
- Tomorrow:
  - PS 7, 9:00AM
  - Lab 8
  - PA 7, 11:59PM

Written Exam 1:



Written Exam 1 over the years



Review from yesterday: Data Compression

Yesterday

- Data Compression
- Information and redundancy
- Huffman Codes

ALOHA

Fixed Width:

0001 0110 1001 0011 0001

20 bits

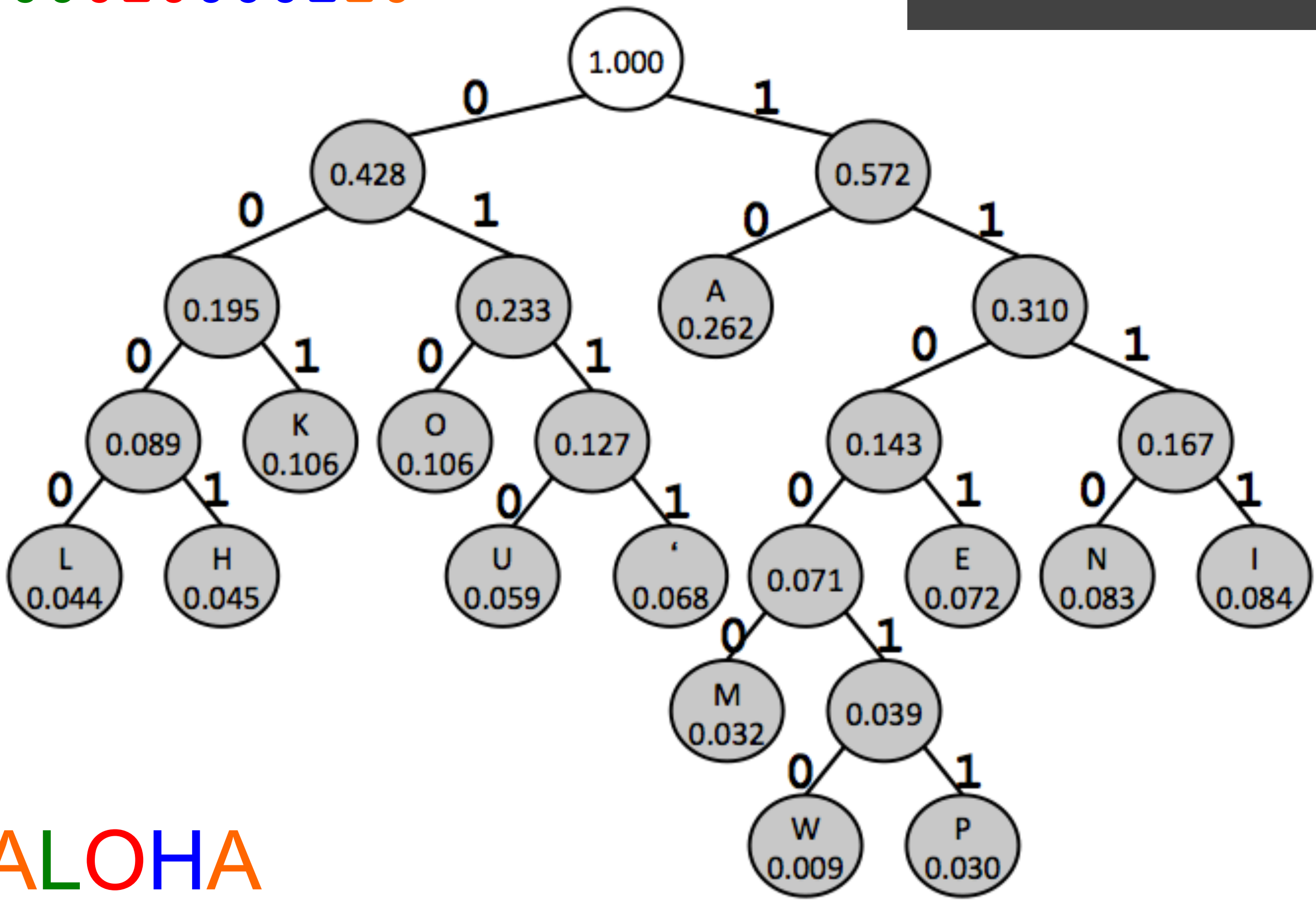
Huffman Code:

10 0000 010 0001 10

15 bits

Decoding

100000010000110



ALOHA

- To find the character use the bits to determine path from root

Today:

- Human sensory systems and digital representations
- Digitizing images
- Digitizing sounds
- Video

Human Sensory Systems

Why Do We Care?

- We want to represent and reproduce sensory experiences – sights and sounds
  - typically this leads to storing a huge amount of data
  - == Digitizing
- Data compression for images and sounds can exploit limits on human senses
  - throw away information not needed for good-quality experience
  - == Compression

Human Limitations

- Range
  - only certain pitches and loudnesses can be heard
  - only certain kinds of light are visible, and there must be enough / not too much light
- Discrimination
  - pitches, loudnesses, colors, intensities can't be distinguished unless they are different enough (**color1**, **color2**)
- Coding
  - nervous systems "encode" experience, e.g. rods and cones in the eye

images

digitizing

Encoding Images:
Vector vs. Raster / Bit-map

- There are two major ways to store images:
  - **Vector graphics**: a series of lines or curves. Expensive to compute but smoothly rescales.
  - **Raster or Bit-map graphics**: an array of pixels. Cheap to compute, but scales poorly.

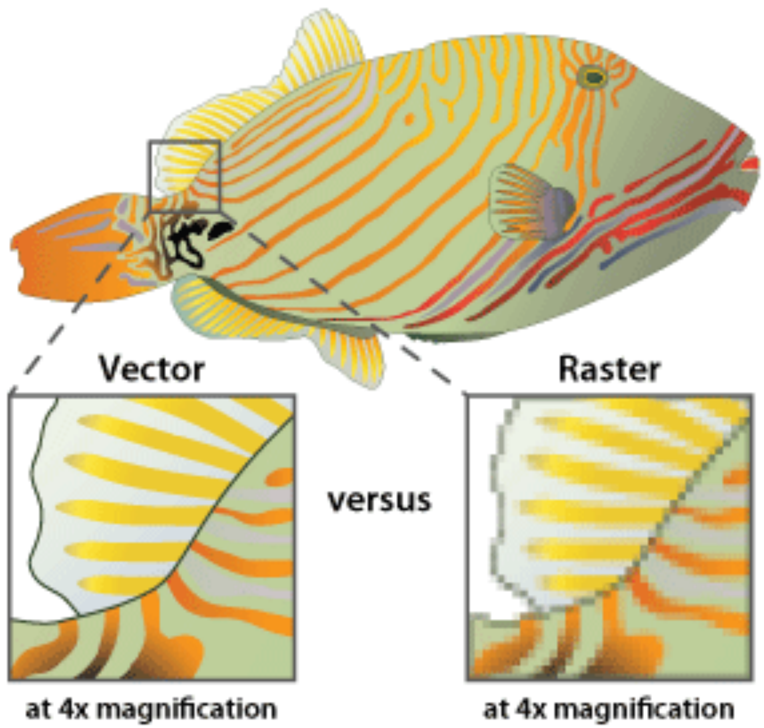
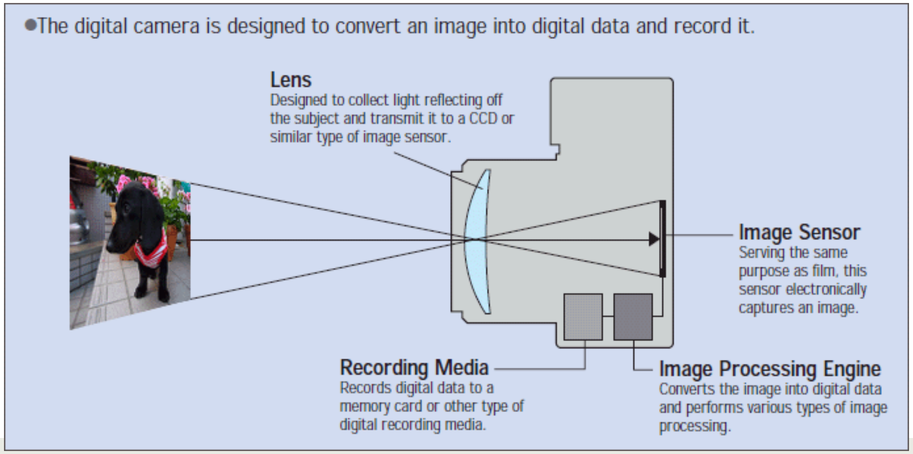


image source: ian.umces.edu

Recording Photographic Images

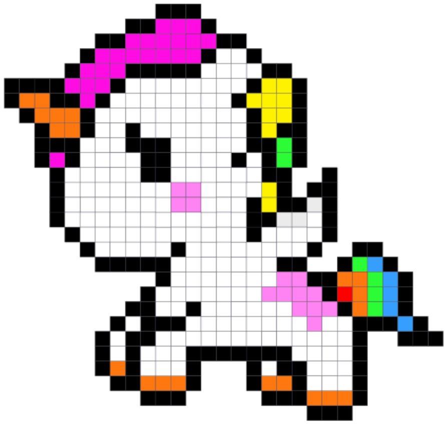
- How do digital cameras record images?
- Basic idea: array of receptors: bit-map
  - each receptor records a *pixel* by “counting” the number of photons that strike it during exposure
- Red, green, blue recorded separately
  - each point on image produced by group of three receptors
  - each receptor behind a color filter



“Raw” Bit-Mapped Images

- Array of pixels
  - one pixel = combination of three colors RGB(red)(green) (blue)
  - RGB → additive primary colors; can be mixed together to create any other color

- What other information do we need to display the image?



“Raw” Bit-Mapped Images

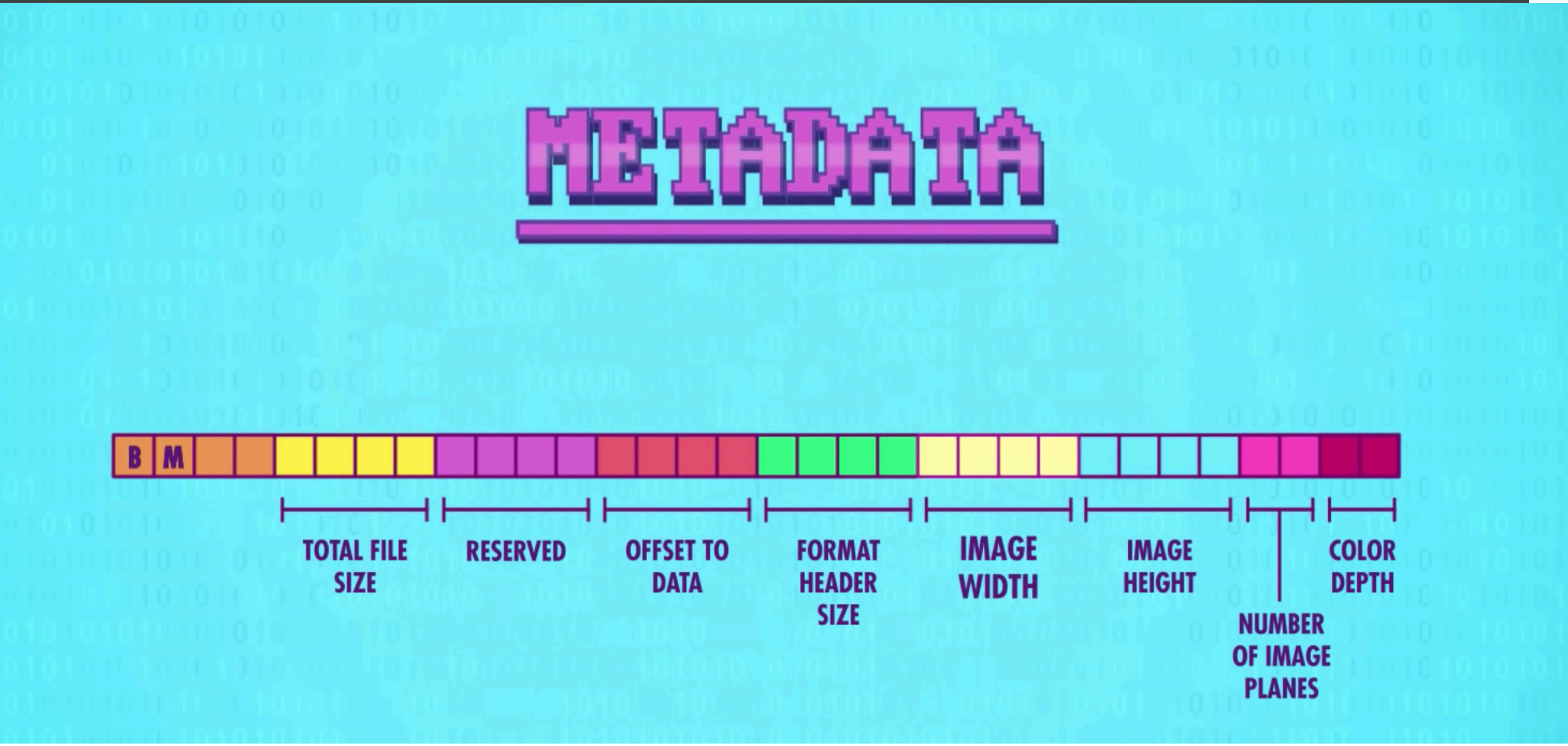


image source: Files & File Systems: Crash course Computer Science #20

“Raw” Bit-Mapped Images

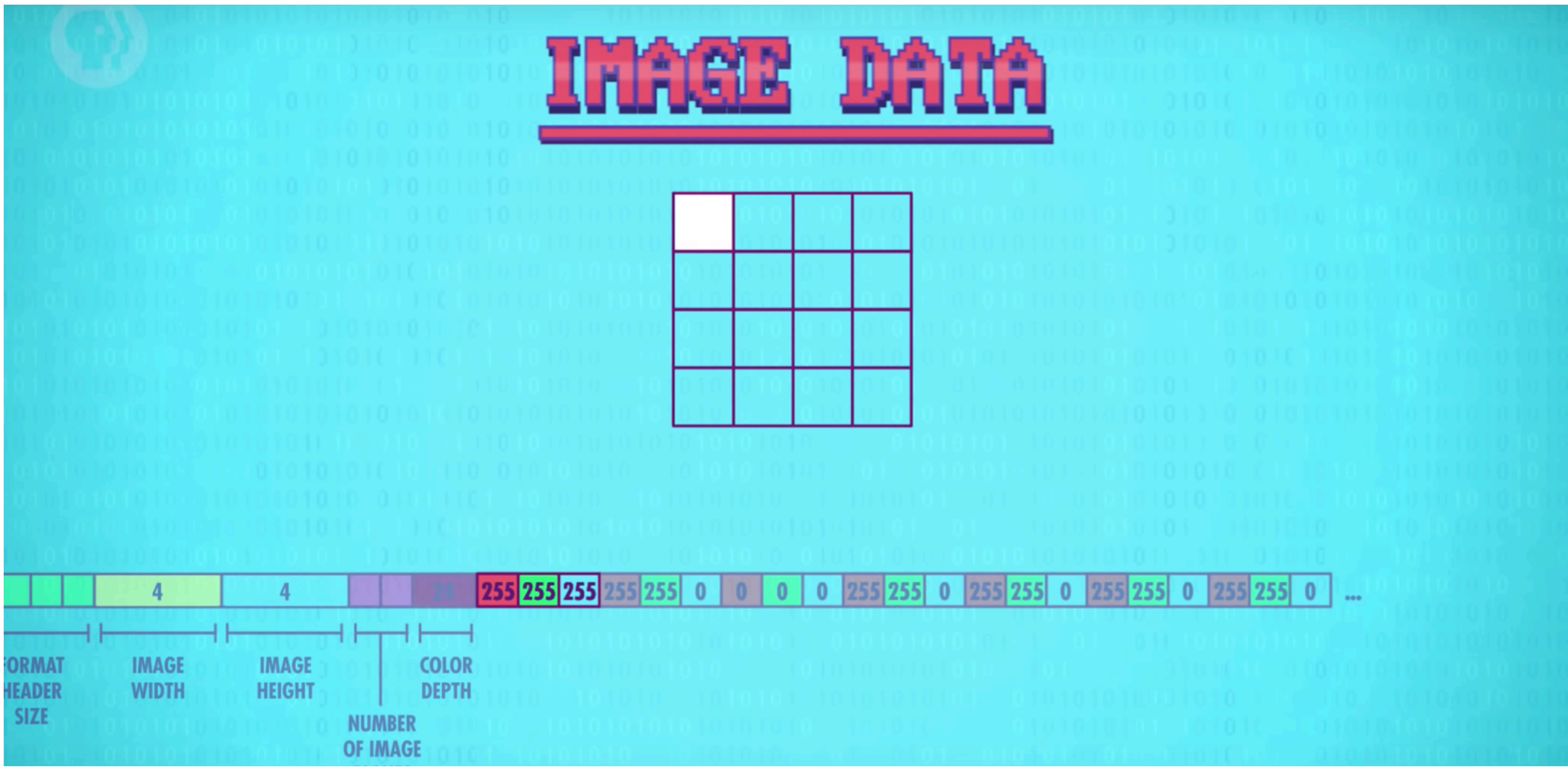


image source: Files & File Systems: Crash course Computer Science #20

"Raw" Bit-Mapped Images

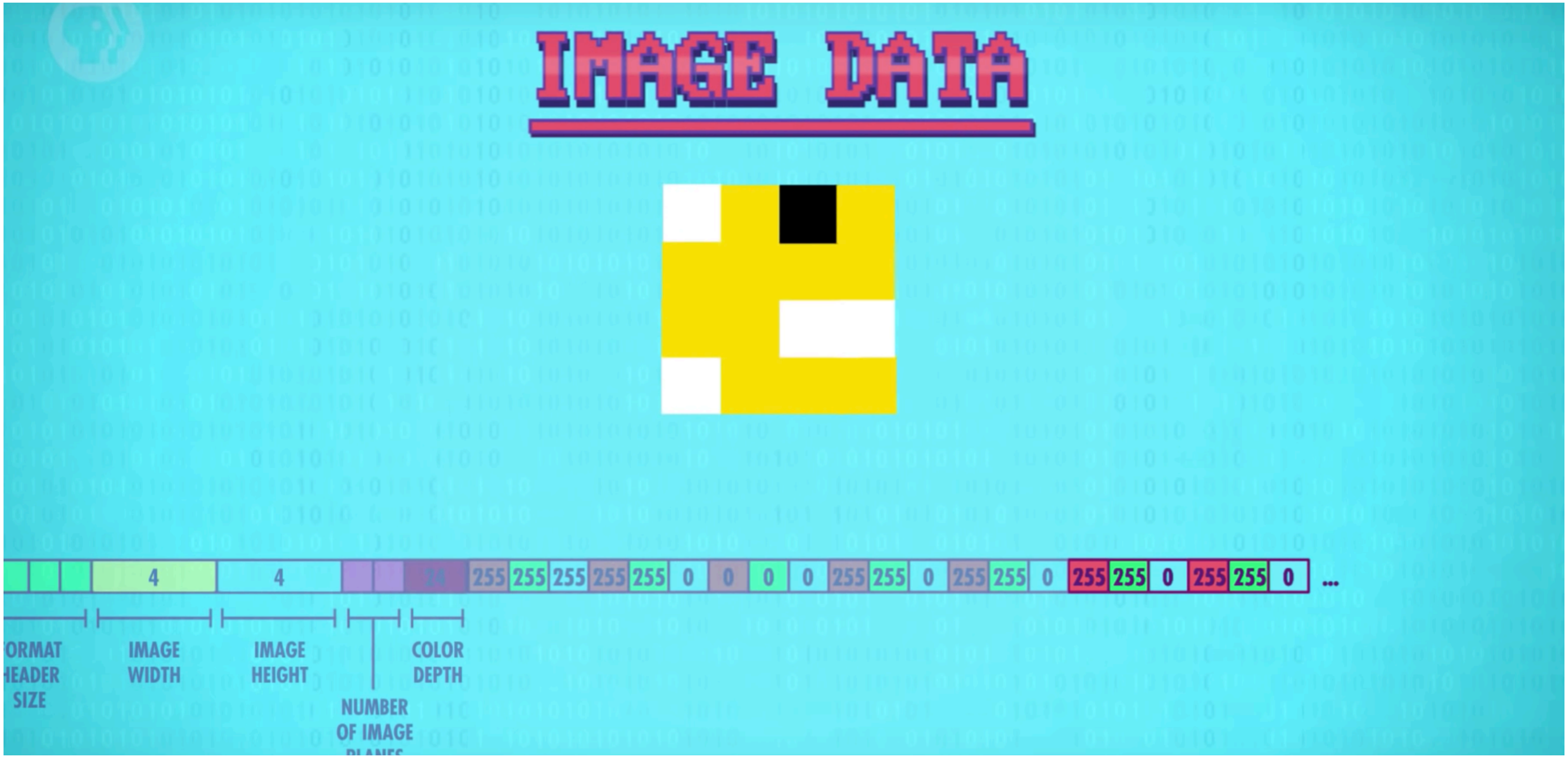


image source: Files & File Systems: Crash course Computer Science #20

Image Formats

- Exploit human perceptual system in quality/size tradeoff
- Exploit specialized types of images to get a lot of compression

Common Standards

- Vector: SVG, EPS, AI, CDR.
  - Special-purpose: commonly used for high-quality illustrations, graphics, etc.

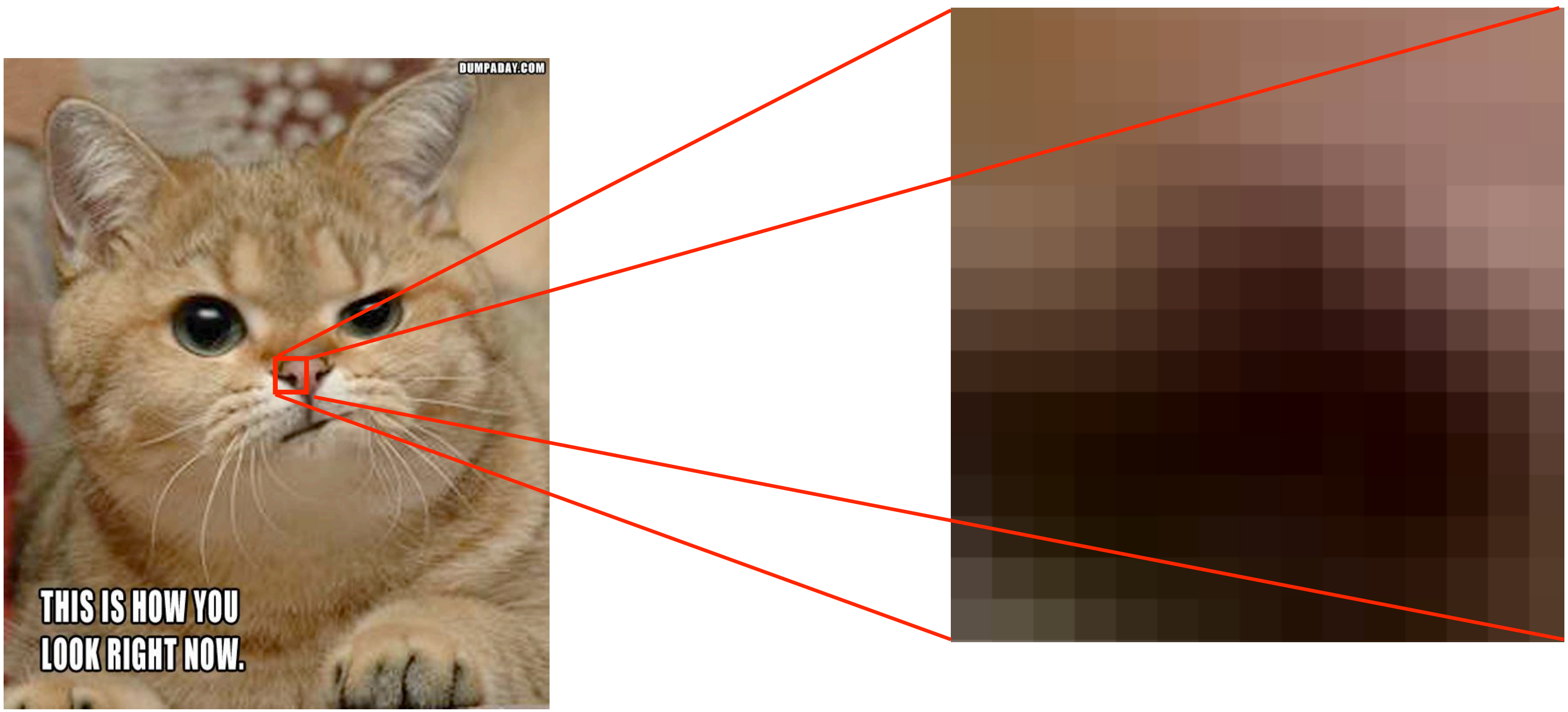
- Raster: JPEG (compression), GIF (compression, transparency), PNG (web portability), TIFF (printing, huge), BMP (huge)
  - Commonly used for photos and pretty much everything

Bit mapped images

A closer look.

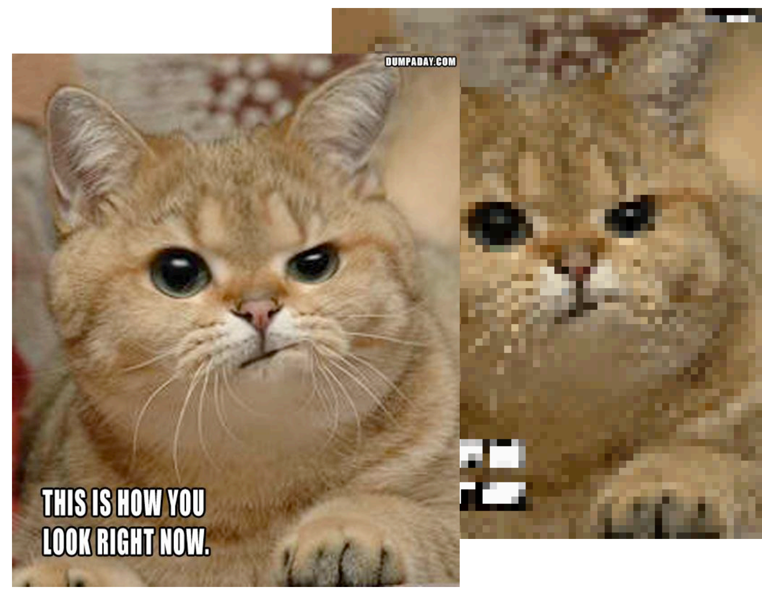
Pixels

- A bit-mapped image is stored in a computer as a sequence of *pixels*, picture elements.



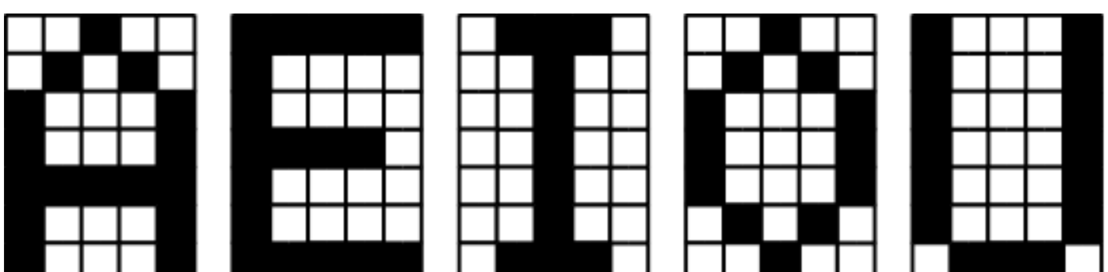
Resolution

- The resolution of an image is the number of pixels used to represent the image
  - 1024 X 768 = 786432 pixels
- Each pixel represents the average color in that region.
- The more pixels per area, the higher the resolution, and the more accurate the image will appear.



Storing Bitmap Images

- In bitmapped images, each pixel is represented in computer memory in binary, just like other data types.
- If pixels of an image are black or white only, then we only need <u>**1 bit per pixel**</u> to store the image, e.g. 00100 might be top row of "A".

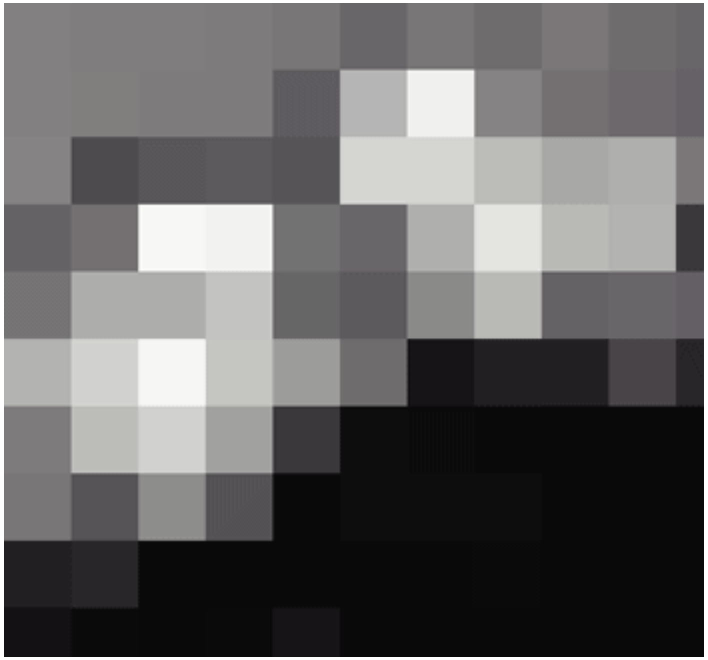


1 bit per pixel

Grayscale Images

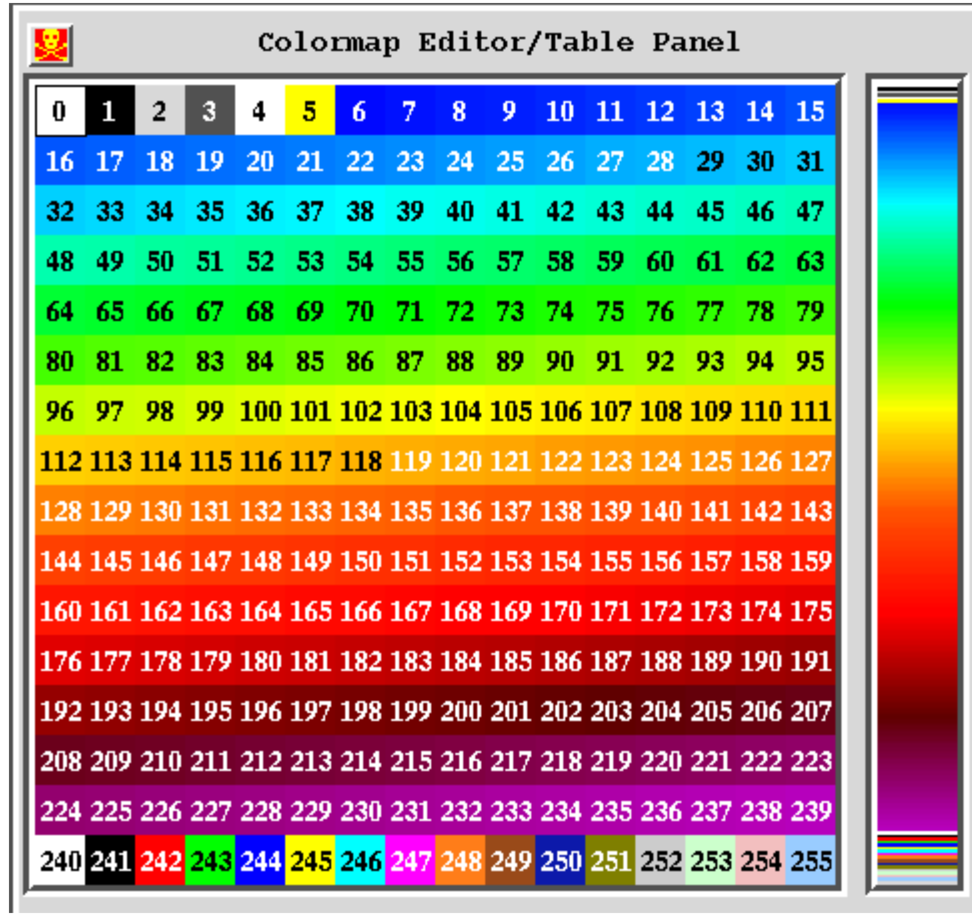
- Grayscale images contain pixels that are various shades of gray, from black (maximum gray) to white (minimum gray).
- If there are 256 levels of gray for pixels, we can represent each **pixel using 8 bits**.
  11111111 = white
  … (shades of gray)
  00000000 = black

8 bits per pixel



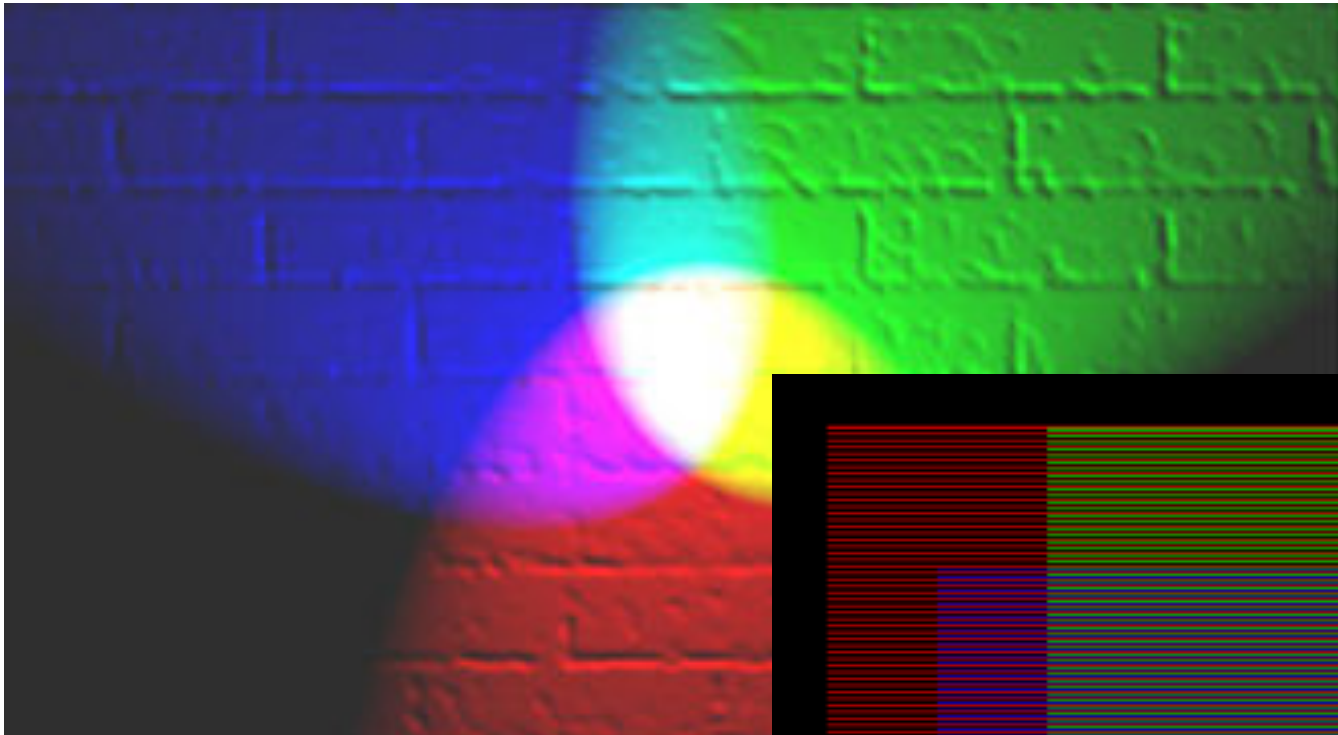
256-color images (8-bit color)

- Each pixel is represented with a 8-bit value that is an index into a *palette* of 256 colors.



8 bits per pixel

RGB color systems

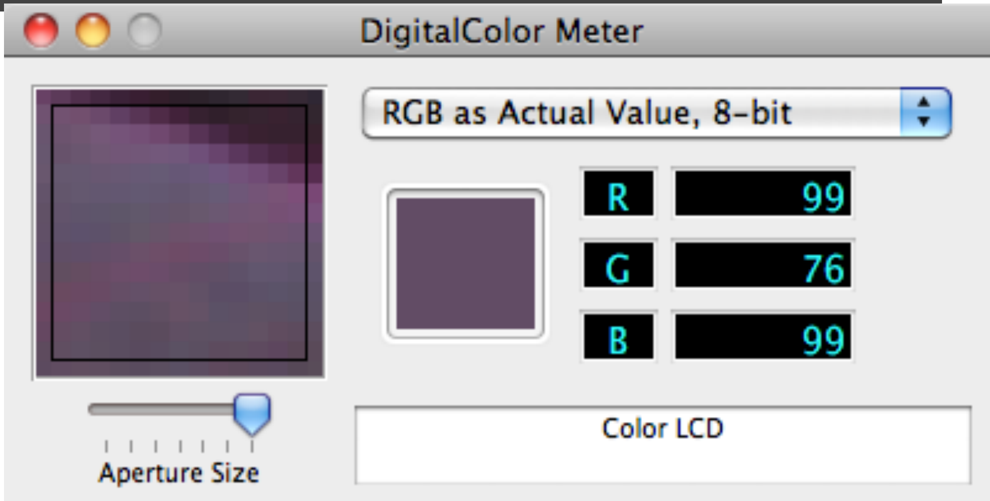


24 bits per pixel

images: Wikipedia

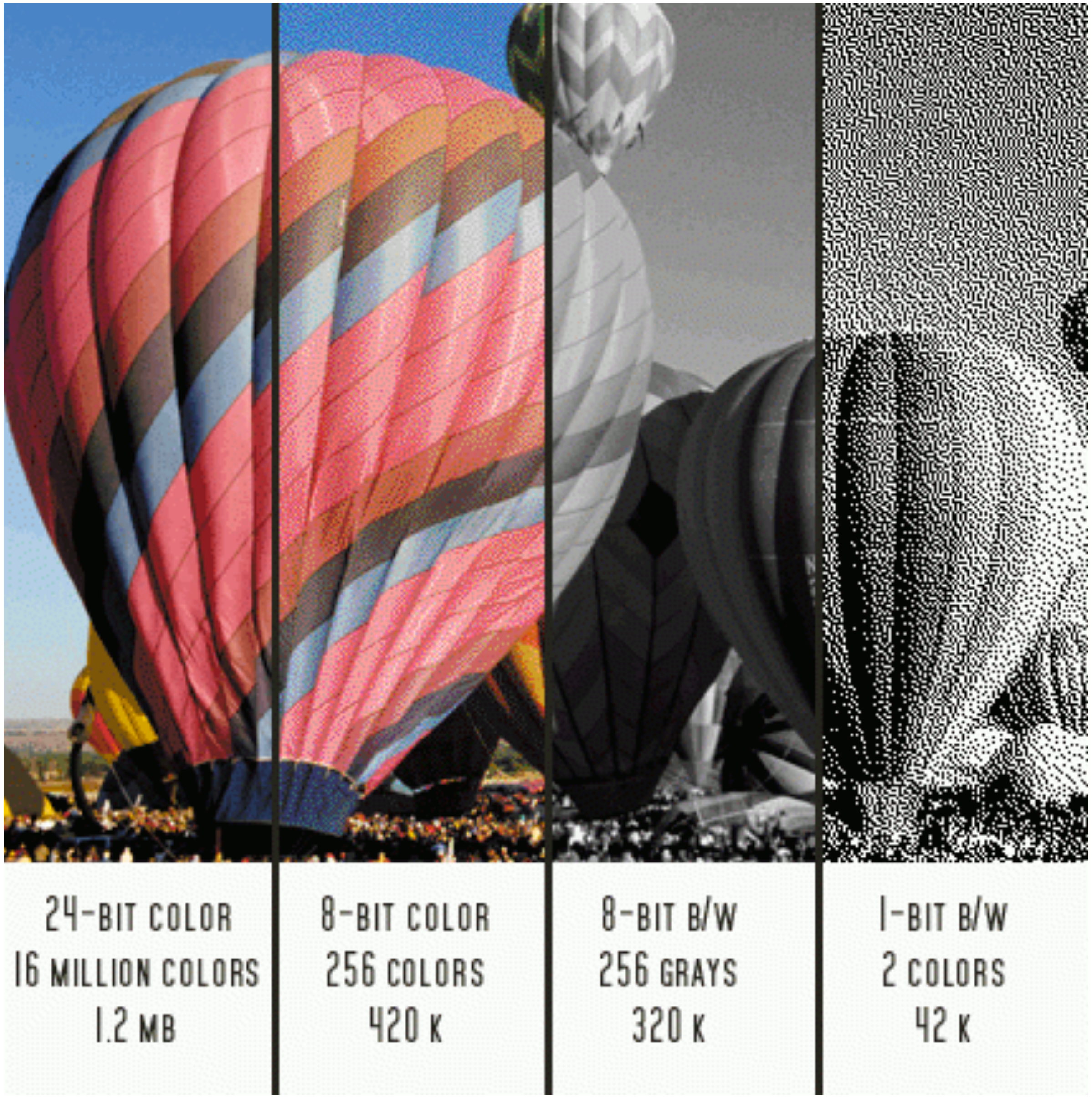
RGB-color images (24-bit color)

- Colors are represented as mixtures of red (R), green (G), and blue (B).
- Each pixel is represented using three 8-bit values, one for each color component.
- This representation allows for 2^{24} = 16,777,216 different colors.
- This representation is also called "true color".
- **Explore with DigitalColor Meter**



(image from Wikipedia)

Comparing


24-BIT COLOR
16 MILLION COLORS
1.2 MB
8-BIT COLOR
256 COLORS
420 K
8-BIT B/W
256 GRAYS
320 K
1-BIT B/W
2 COLORS
42 K

Comparing Representations

- For a 640 X 480 image (307,200 pixels), **how many bytes** needed?

		# of bits	# of bytes
B&W	1 bit per pixel	307,200*1 bits	38,400 bytes
8-bit grayscale	8 bits per pixel	307,200*8 bits	307,200 bytes
256-color (8-bit color)	8 bits per pixel	307,200*8 bits	307,200 bytes
24-bit color	24 bits per pixel	307,200*24 bits	921,600 bytes (307,200*24/8)

- A single RGB image of size 1600 X 1200 requires over 5.76 million bytes!

so we need compression

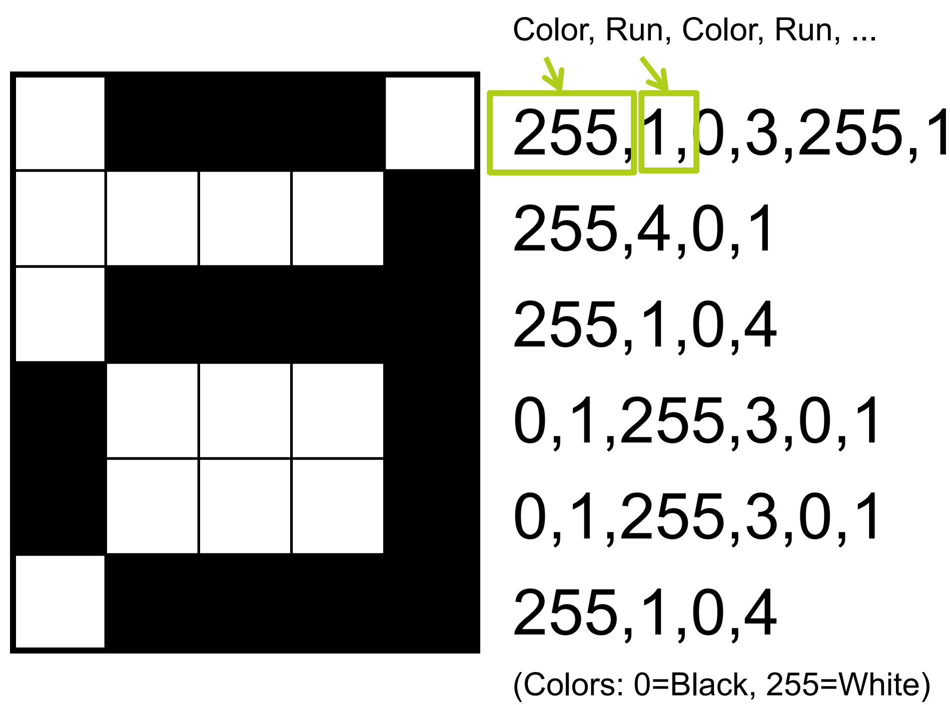
Compressing images

Compressing Raster Data

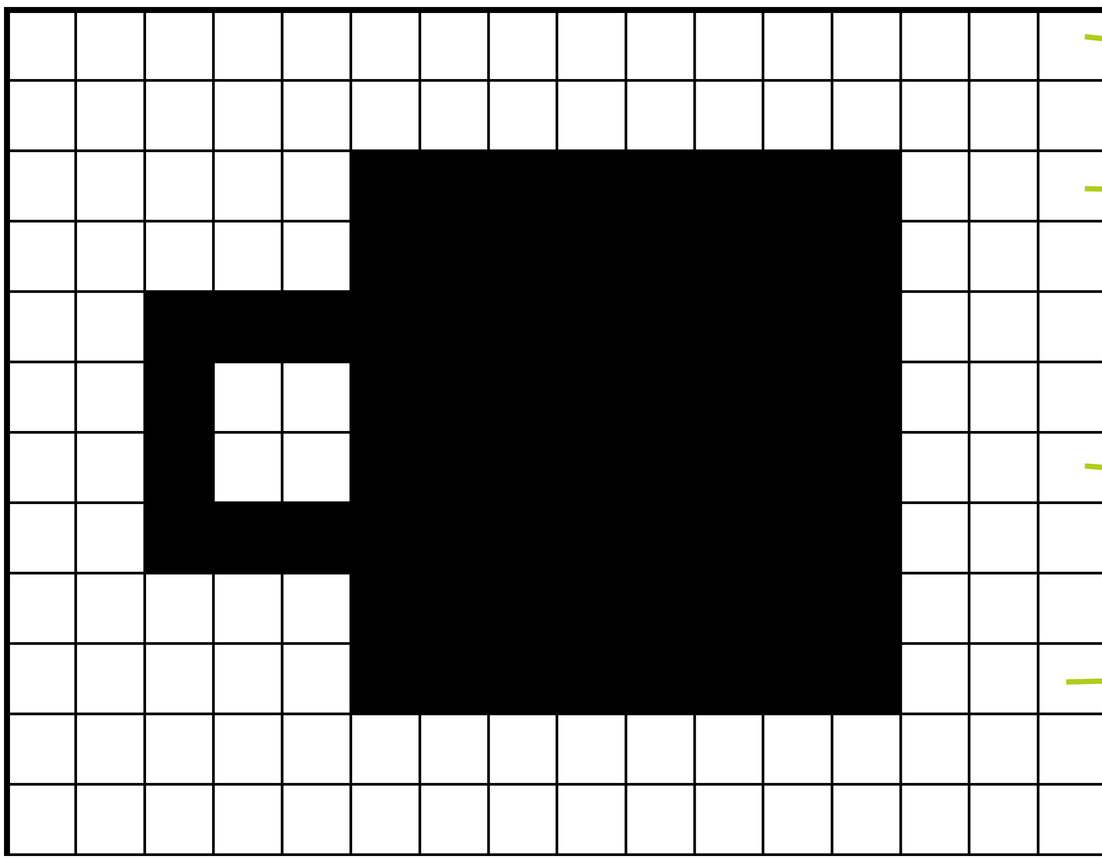
- Run-length encoding (lossless, limited)
- Color maps (GIF, good for graphics with solid areas of color)
- JPEG (lossy - a suite of techniques exploiting human visual perception)

RLE compression

- Run-Length Encoding is a lossless compression technique used in early image files.
- Instead of storing the 8-bit value for every pixel, we store an 8-bit value along with how many of these occur in a row (run).
- This saves a lot **when there are large runs of the same color**.



RLE Comparison



RLE	Bitmap
2 bytes	16 bytes
2 bytes	16 bytes
6 bytes	16 bytes
6 bytes	16 bytes
6 bytes	16 bytes
10 bytes	16 bytes
10 bytes	16 bytes
6 bytes	16 bytes
6 bytes	16 bytes
6 bytes	16 bytes
2 bytes	16 bytes
2 bytes	16 bytes
64 bytes	192 bytes

GIF: Graphic Interchange Format

- 8-bit pixels, mapping to a table of 256 24-bit RGB colors.
- A *codebook* stores recurring sequences.
- Useful for representing images with fewer colors or large areas of color like company logos.

GIF and photos

Only 256 colors leads to strange effects

JPEG (JPG): Joint Photographic Experts Group

- A lossy compression technique for photographic images.
  - Perceptual Coding: based on what we can/ cannot see.

Higher quality
Compression 2.6:1
(images from Wikipedia)

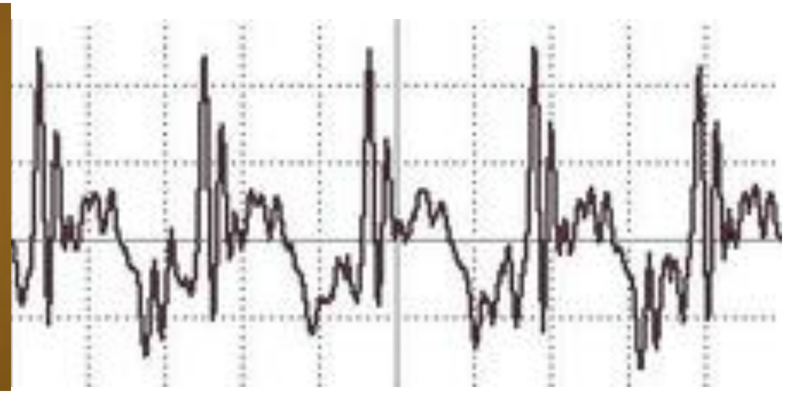
Medium quality
Compression 23:1

Lowest quality
Compression 144:1

Digitizing sound

Sound Is a Pressure Wave

- When an instrument is played or a voice speaks, periodic (many times per second) changes occur in air pressure, which we interpret as sound.

Human Sound Perception

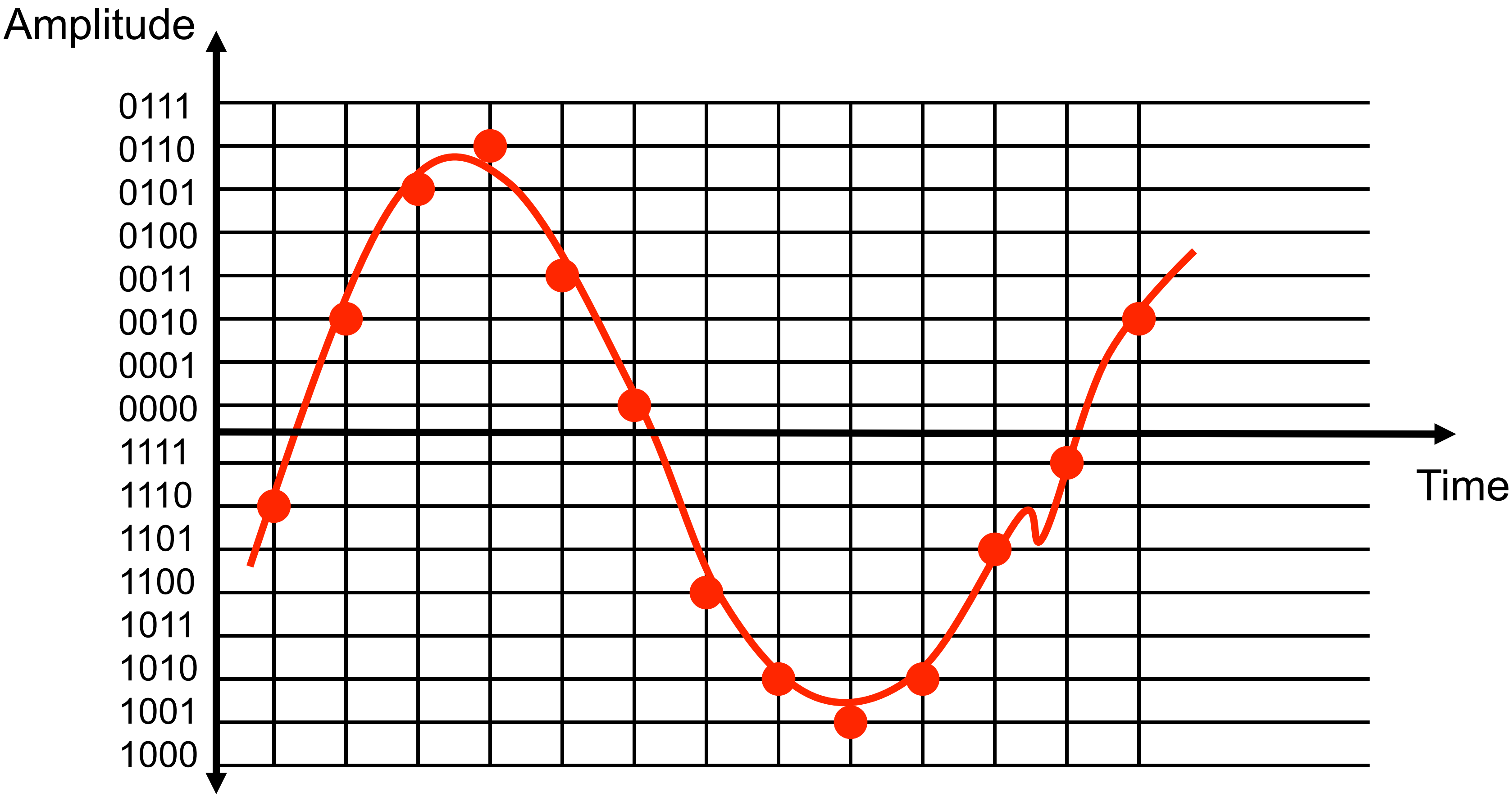
- Frequency **range**:
  - about 20 Hz* to 20,000 Hz
- Frequency **discrimination**
  - drops off at high part of range
- Amplitude (roughly, volume) **range**:
  - about 10^9 (huge!)
- **Sensitivity** to volume (amplitude)
  - drops off at ends of range

* *Hz* stands for *Hertz*, meaning *cycles per second*

Sampling

- Pressure varies **continuously**
  - **sampling** measures how much pressure at fixed intervals
- Accuracy determined by
  - Sampling rate
  - Sample size
- **Sampling rate**: how many times per second do we measure?
- **Sample size**: how many bits do we store per sample?

Sampling



1110 0010 0101 0110 0011 0000 1100 1010 1001 1010 1101 1111 0010 ....

When Sampling Is Too Slow

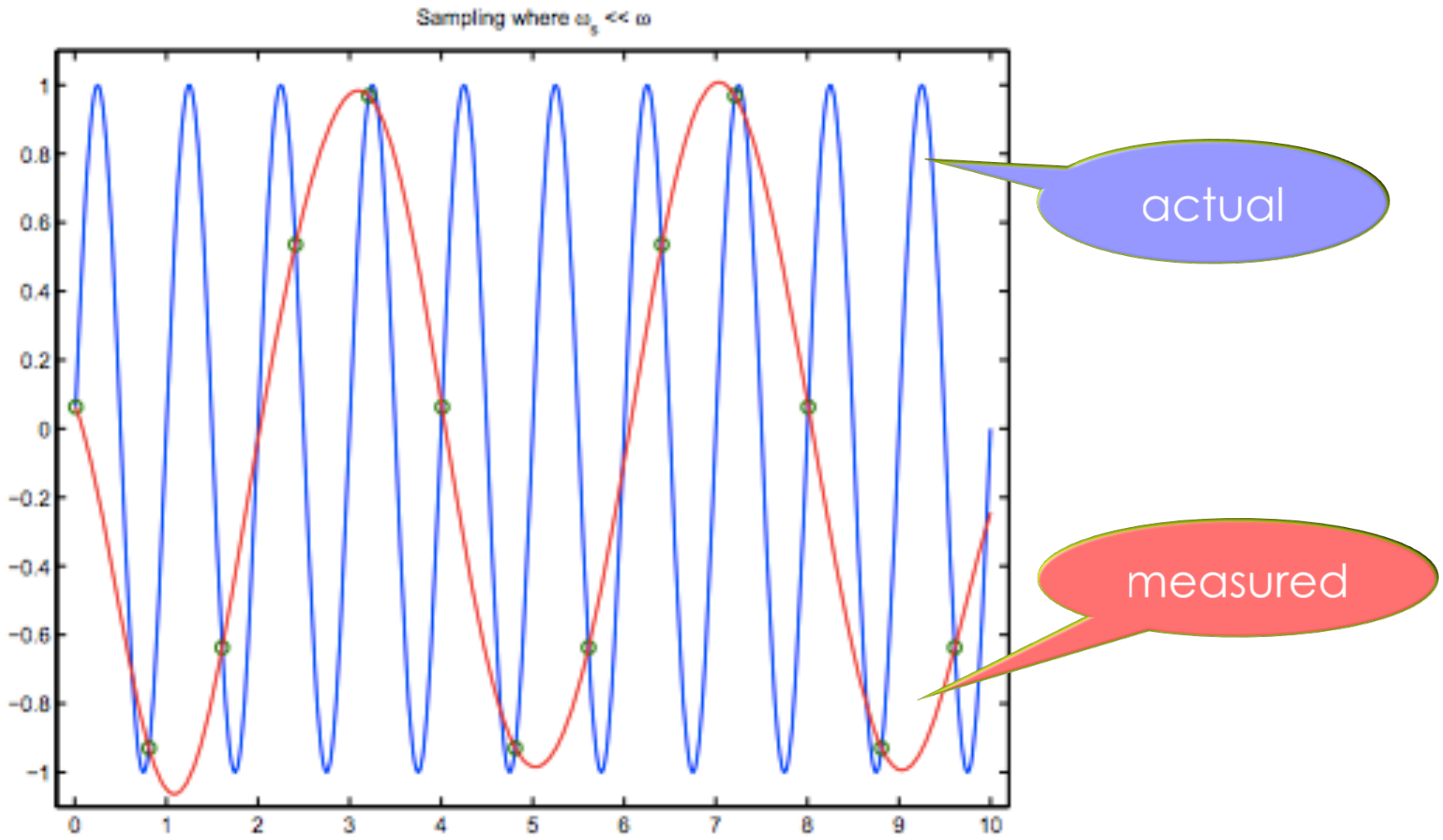


Figure 5.7: Sampling a sinusoid at too slow of a rate.

Source: http://www.princeton.edu/~cuff/ele201/kulkarni_text/digitizn.pdf

Samples Must Have Enough Bits

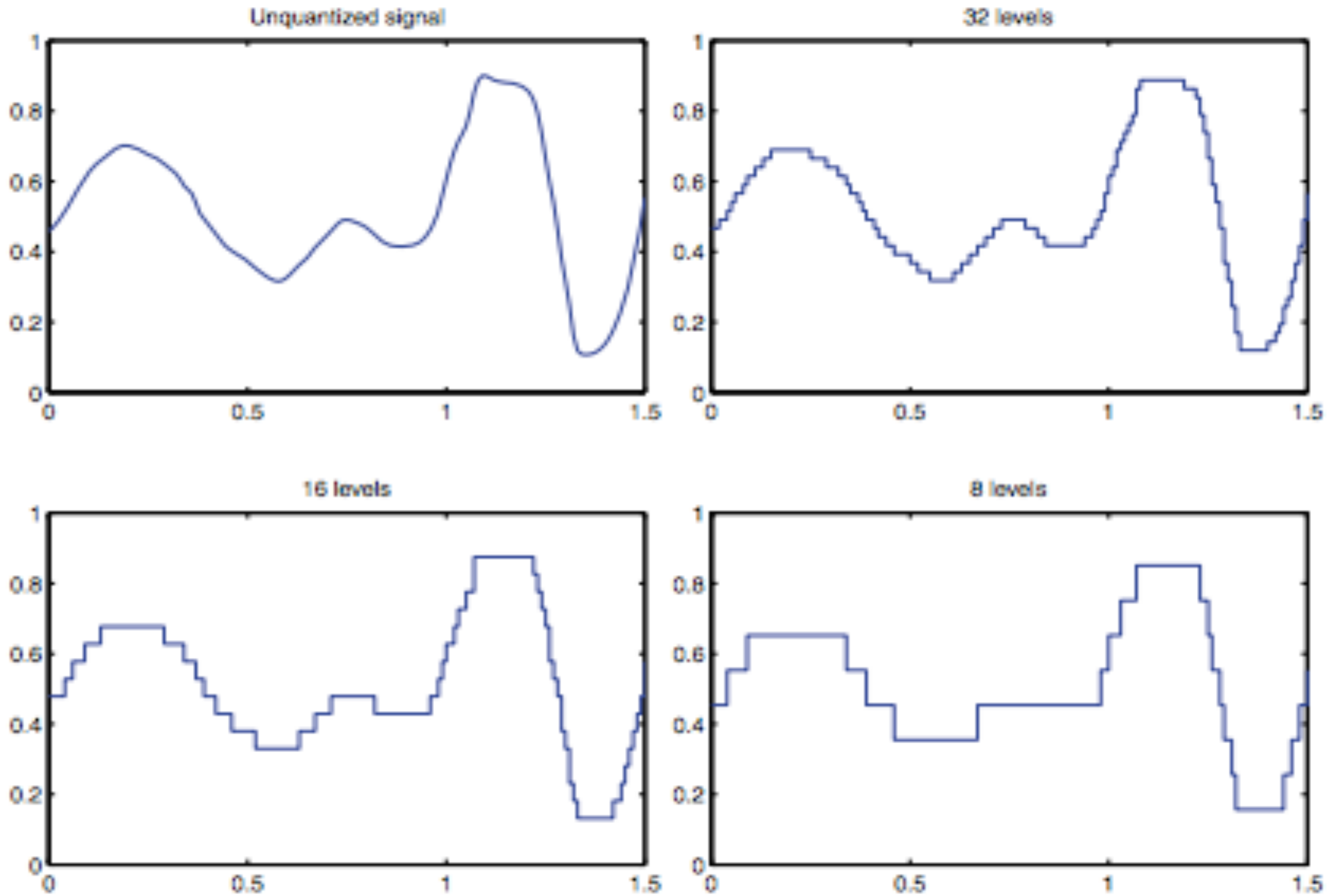


Figure 5.11: Quantized versions of an analog signal.

Source: http://www.princeton.edu/~cuff/ele201/kulkarni_text/digitizn.pdf

High-Quality Sampling

sampling rate

- **Rate**: 44,100 samples per second (Hertz – Hz).
  - sampling theorem: *the sampling rate must be at least twice the highest frequency in the sound* (humans can hear up to approx. 20,000 Hz.)

sample size

- **Sample size**: 16-bits per sample (so there are 65,536 amplitude levels that can be measured).
  - *Quantization* (rounding to integer sample values) *introduces noise*. Adding one bit cuts the noise in half.

sound file formats

Compressing Sound Files

- *codecs* (compression/decompression) implement various compression/decompression techniques
- **Lossless**: WMA Lossless, ALAC, MPEG-4 ALS, …
- **Lossy**: MPEG (like JPEG) a family of perceptually-based techniques

MP3

- MP3 (MPEG3) is a <u>lossy</u> compression technique.
- Takes advantage of human perception (**psychoacoustics)**
  - Our hearing is better in mid range frequencies than on the low and high ends.
  - If a loud and soft sound play at about the same time or about the same frequencies, we can't hear the soft sound: this is called *masking*
  - *Masking can hide noise introduced by compression*.

MP3 Demo

Let Me Call You Sweetheart

http://www-mtl.mit.edu/Courses/6.050/2014/notes/mp3.html

MP3 Compression

- Like JPEG, MP3 has various levels of compression:

Bit Rate	Compression Ratio	Quality
256Kbps	5:1	Supreme (near best)
192Kbps	7:1	Excellent (better)
128Kbps	11:1	(good)
96Kbps	19:1	(fair)
64Kbps	22:1	FM quality (poor)

- MP3 also has Variable Bit Rate (VBR) since compression ability can vary at different segments of the digital recording.

image + sound = video

Problem: a torrent of data

- Imagine if we used "raw" images and sound for video
  - about 5MB of image data per frame, times 30 frames/sec = about 150 MB image data per second
  - about 1400 kbps, or 175 KB sound data per second
  - 10 minutes of this: about 90.1 Gigabytes

MP4

- MP4 (MPEG4): compression technique for video
- Sophisticated engineering exploits
  - **redundancy** (next frame is likely to resemble this frame)
  - **perception** (what the eye and ear can do)
- Applications: streaming, HDTV broadcast, Digital Cinema, cameras (e.g. GoPro), phones

YouTube, Vimeo, etc.

- YouTube, Vimeo, etc. support many formats, including MP4, AVI (Microsoft), QuickTime (Apple), and Flash (Adobe).
- You can download videos from these sites in your preferred format using tools such as KeepVid
- Uploading and then downloading a video may reduce the quality due to lossy compression.

Summary

- **Samples**
  - **Pixels** are samples of the image in space; *resolution* and *number of bits* determine quality
  - **Audio samples** measure the signal in time; *sampling rate* and *number of bits* determine quality
- **Tradeoff** between quality and size
- **Compression** methods exploit
  - Coding redundancy (e.g. Huffman codes)
  - Data redundancy (e.g. run-length coding)
  - Perceptual redundancy (e.g. MP3, JPEG)