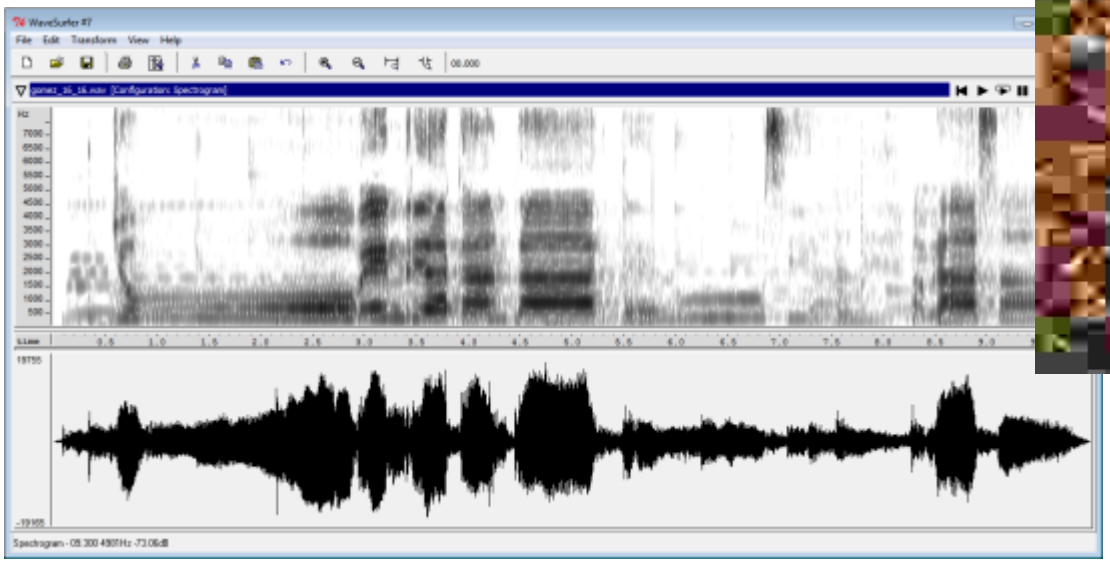
Lossy compression



$$Q = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}.$$

Overview

- Digital audio
  - Sampling rate
  - Quantization
  - MPEG audio layer 3 (MP3)
- JPEG still images
  - Color space conversion, downsampling
  - Discrete Cosine Transform (DCT)
  - Quantization
  - Encoding

http://www.vectronicsappleworld.com/collection/appleiie.html

Kate Bush 50 Words for Sno

https://www.hdtracks.com/index.php?file=catalogdetail&valbum_code=HD045778718603

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The Classic 100

Artists

Genres

Artists | Kate Bush | 50 Words for Snow

Audiophile 96kHz/24bit

Title: 50 Words for Snow
Artist: Kate Bush
Genre: Pop
Label: Anti-/Epitaph
Release Date: 2011

50 Words For Snow is the latest release from British singer-songwriter Kate Bush, an artist who has been cited as a source of inspiration from the likes of Tori Amos and Bjork. With her multi-octave vocals and eloquent piano playing, Bush delivers another boundary defining album full of lyrical landscape. The winter themed album features seven new compositions and collaborations with guest musicians: Elton John, Andy Fairweather Low, Stephen Fry and Steve Gadd.

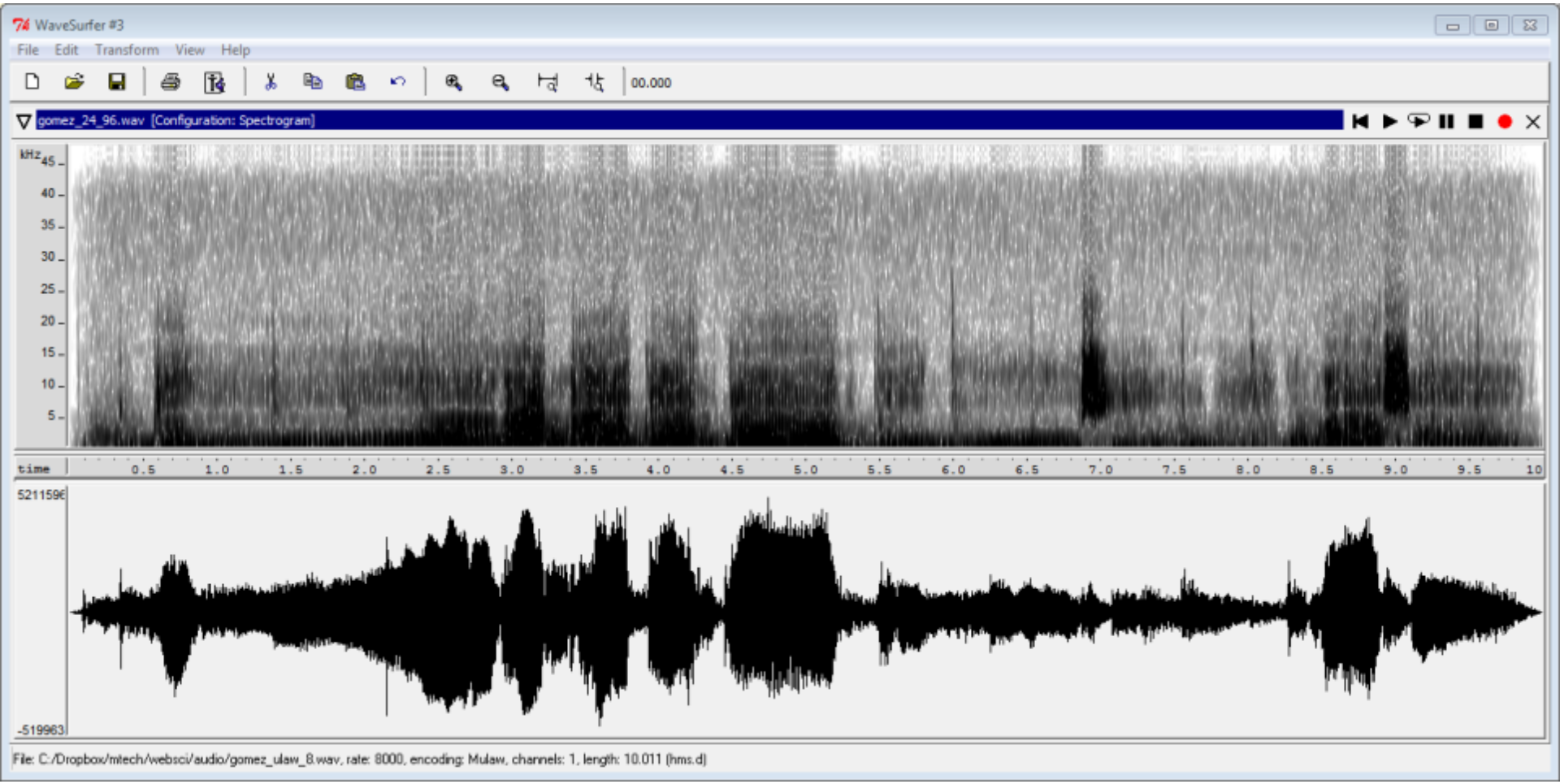
Which Format Should I Download?

Explore Album

Buy Album	Length	Format	Price	Add
50 Words for Snow	1:04:57	flac	$17.98	

Buy Individual Tracks

#	Track Title	Length	Listen	Format	Price	Add
1	Snowflake	9:46			Album only	
2	Lake Tahoe	11;08			Album only	
3	Misty	13:32			Album only	
4	Wild Man	7:16			Album only	
5	Snowed In At Wheeler Street	8:05			Album only	
6	50 Words for Snow	8:30			Album only	
7	Among Angels	6:48			Album only	

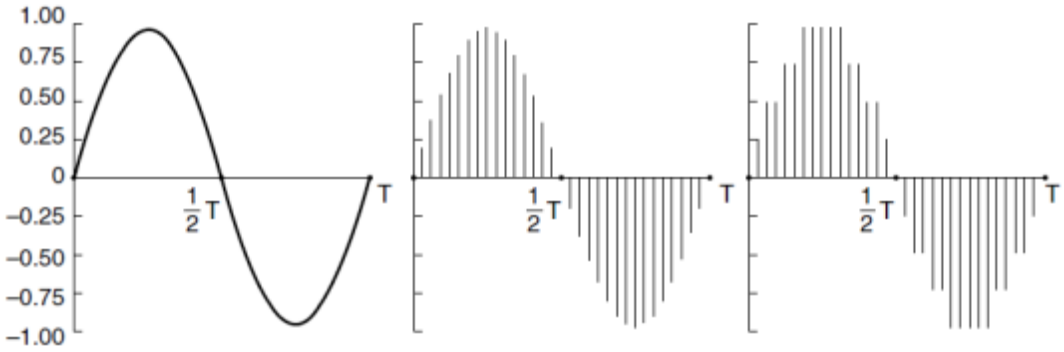


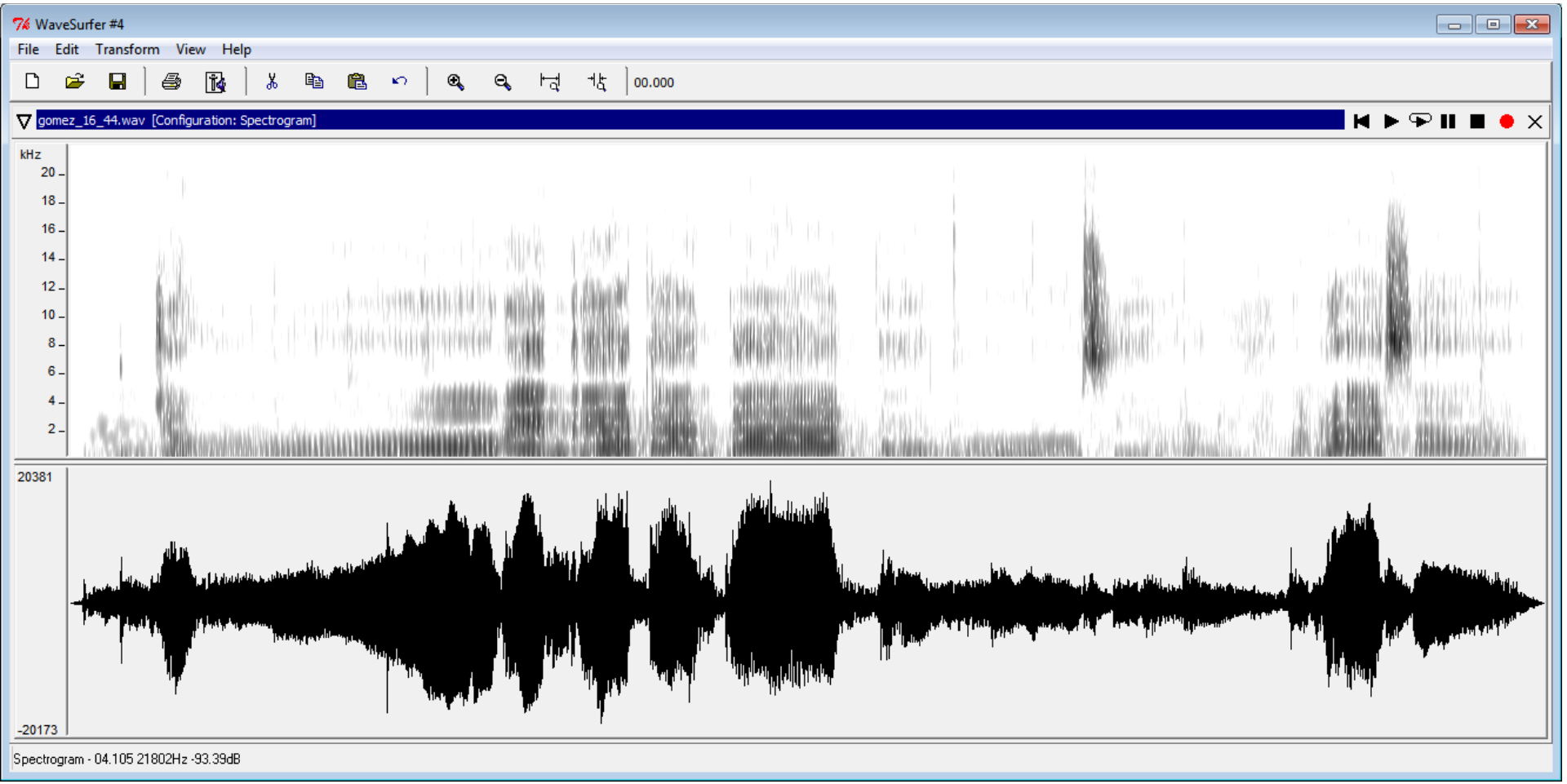
- Studio quality audio
  - 96kHz sampling
  - 24 bits / sample
  - 2 channels
- Stats
  - 10s = 3,411 KB
  - 2729 kbps
  - FLAC loseless, maximum

flac
free lossless audio codec

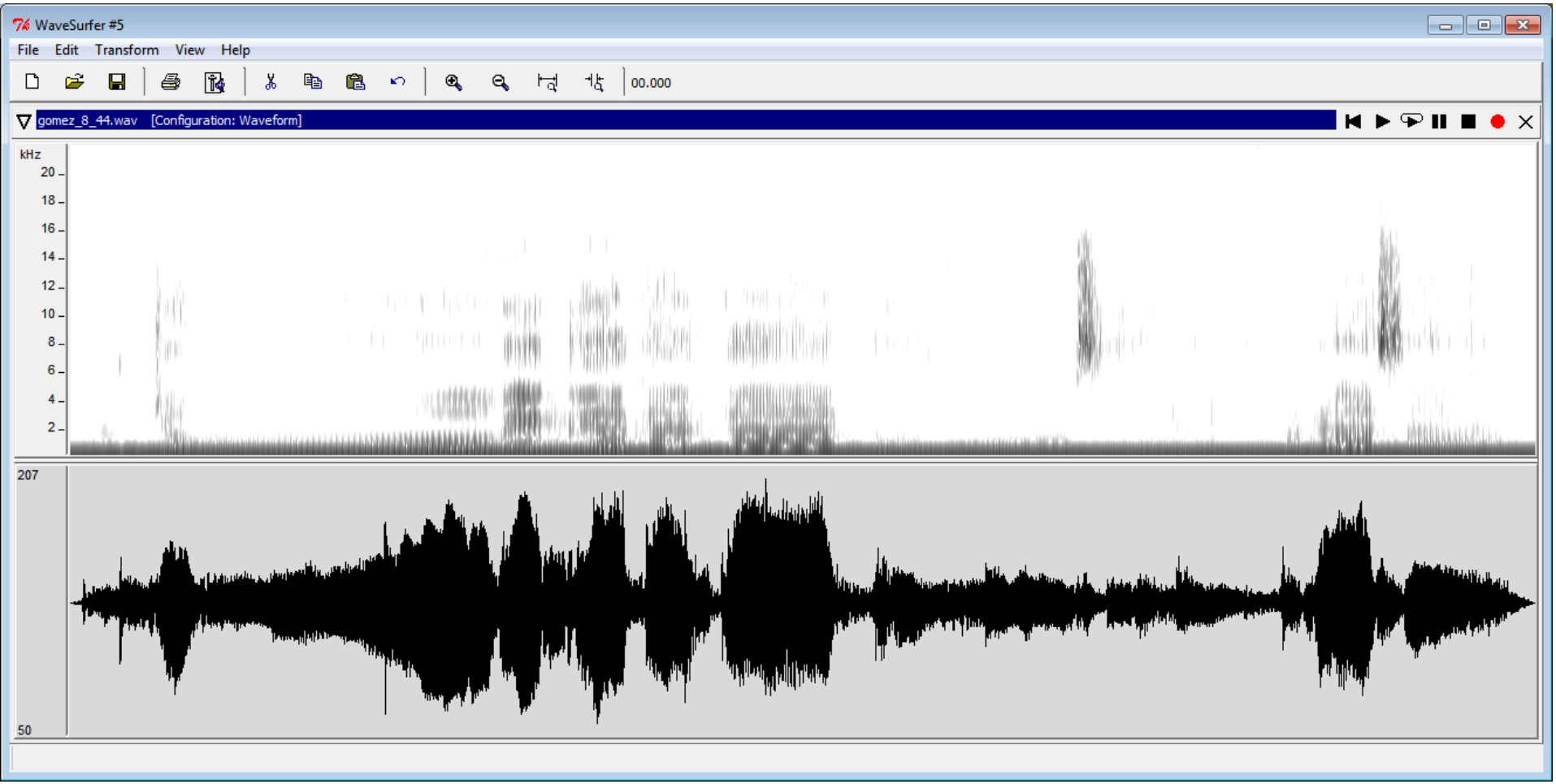
Digital audio

- Analog-to-Digital Converter (ADC)
  - Sampling rate of analog waveform
    - 96 kHz (studio)
    - 44.1 kHz (CD)
    - 8 kHz (telephone)
  - Bits per sample
    - 24 bits (studio)
    - 16 bits (CD)
    - 8 bits (telephone)
  - Number of channels
    - 1 = mono, 2 = stereo

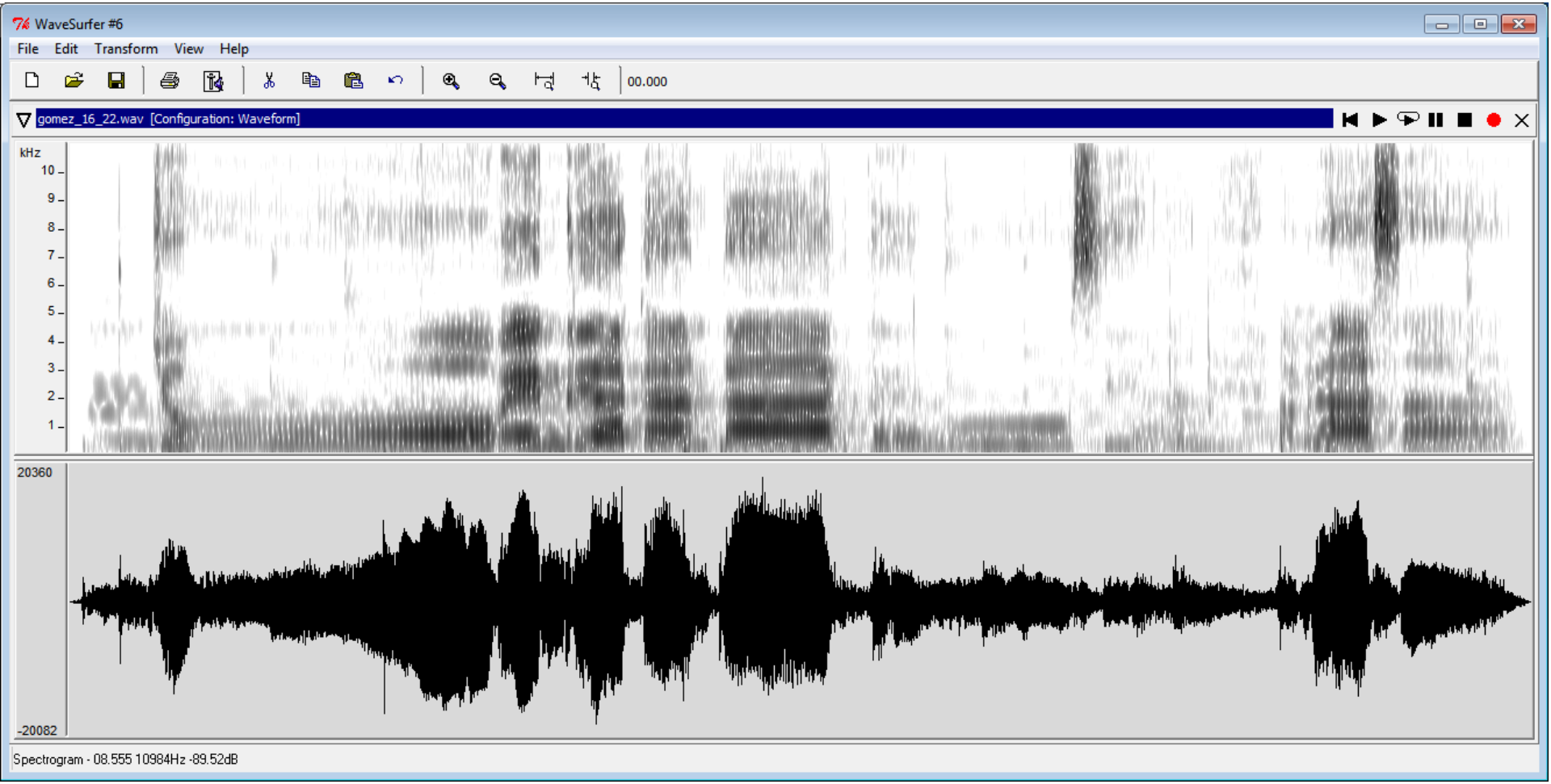




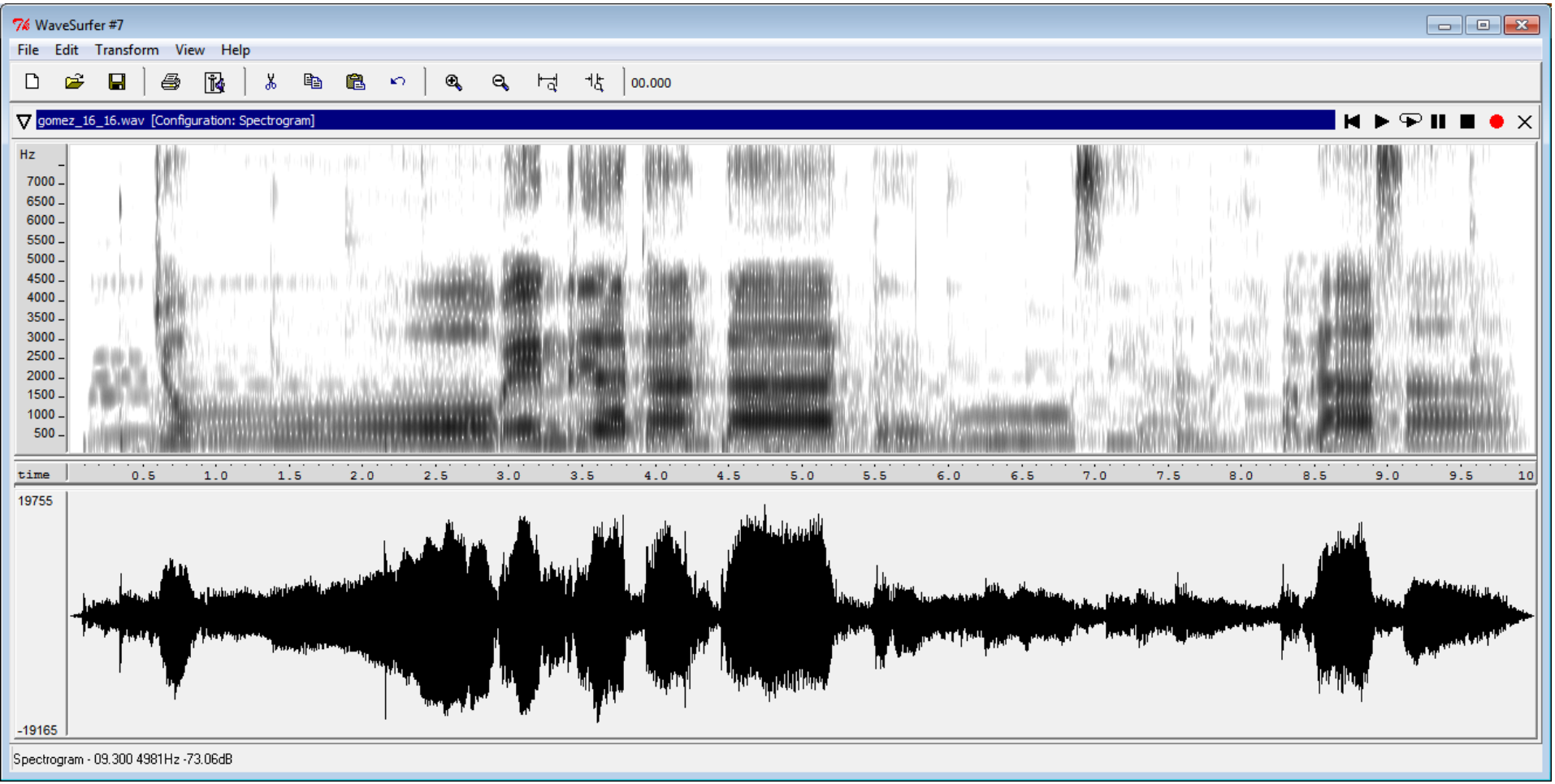
- CD quality audio
  - 44.1 kHz sampling
  - 16 bits / sample
  - 2 channels
- Stats
  - 10s = 831 KB
  - 665 kbps
  - FLAC loseless



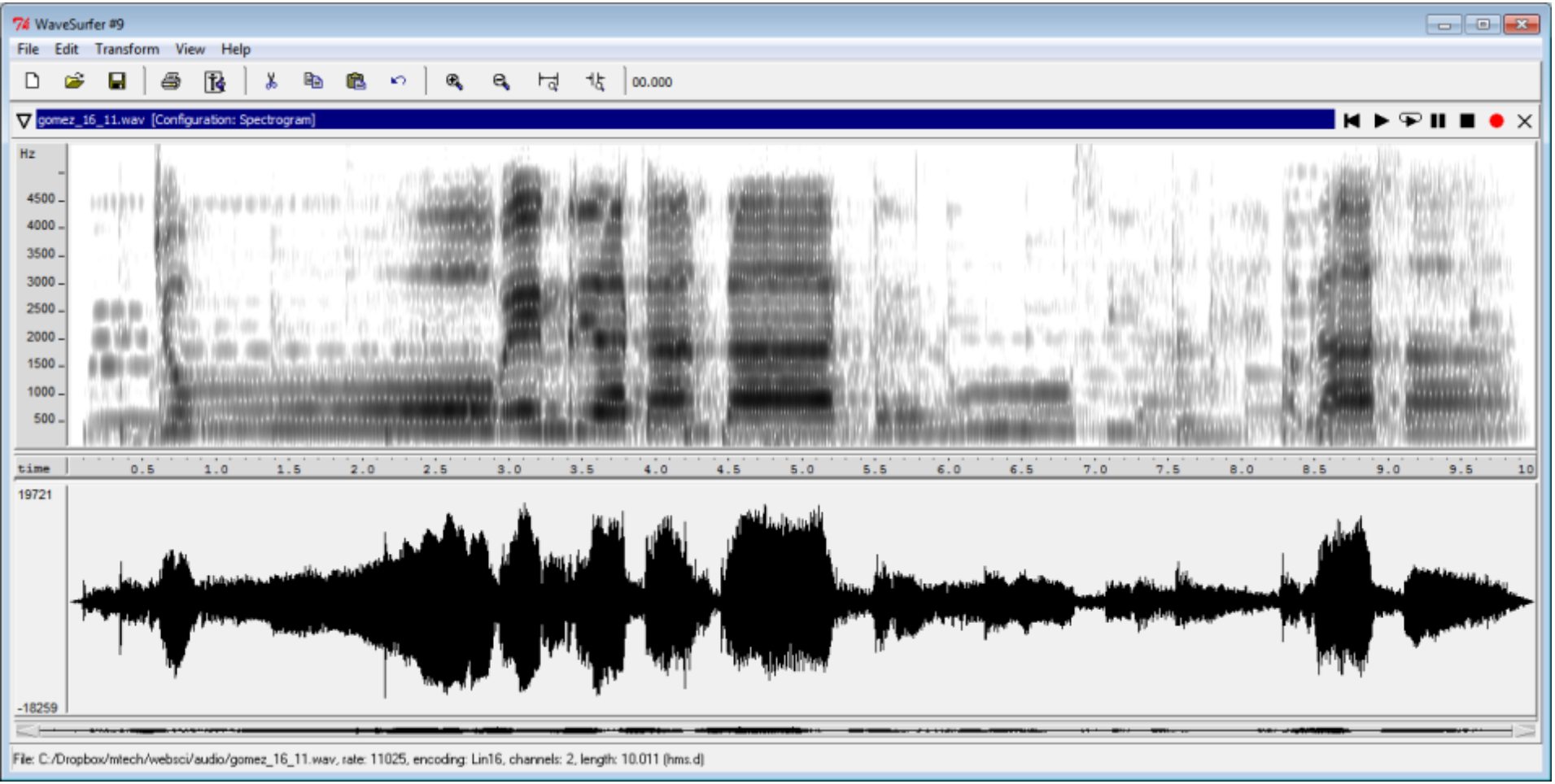
- 8-bit sampling rate
  - 44.1 kHz sampling
  - 8 bits / sample
  - 2 channels
- Stats
  - 10s = 211 KB
  - 169 kbps
  - FLAC loseless



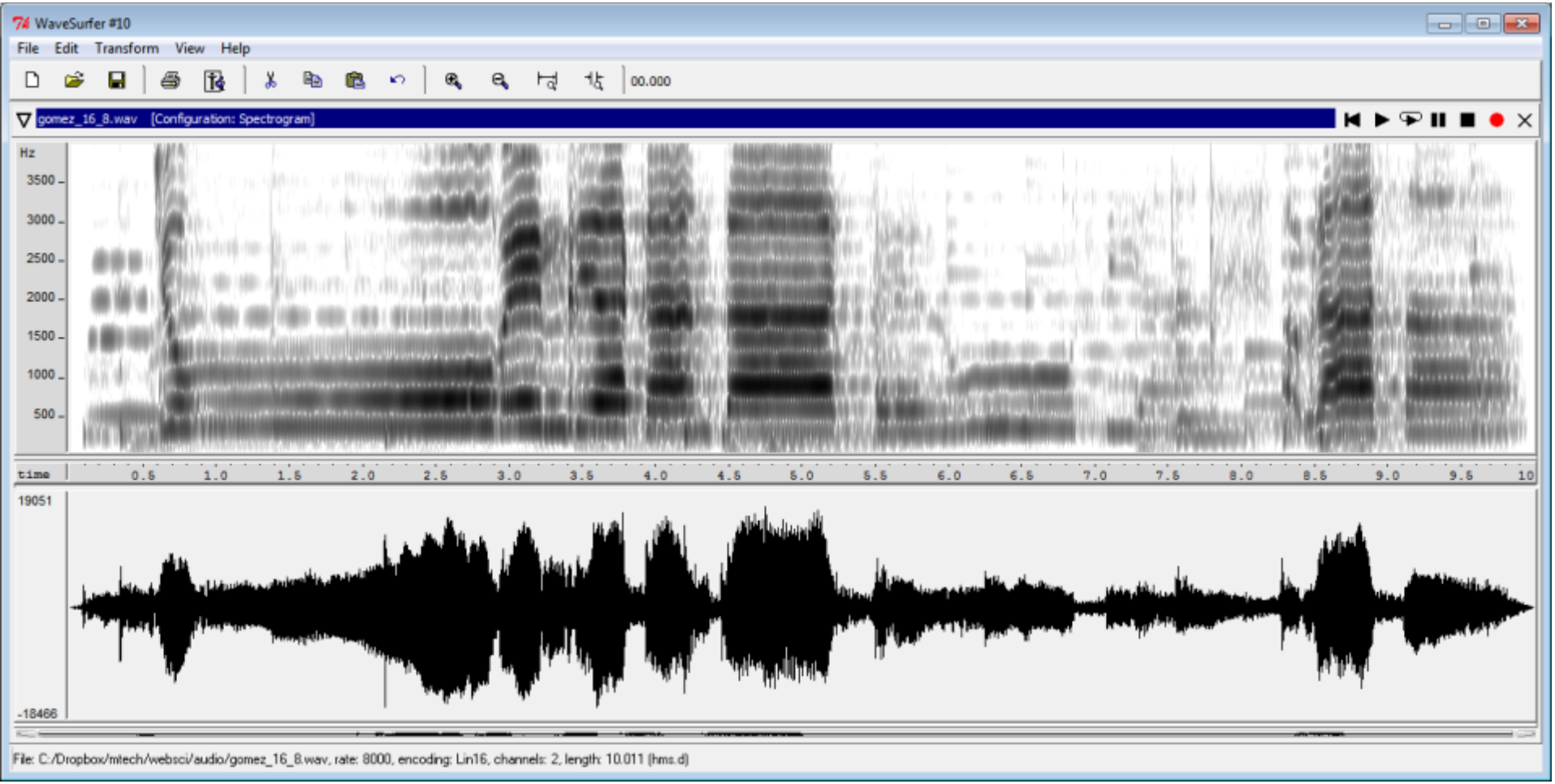
- 22 kHz sampling rate
  - 22.05 kHz sampling
  - 16 bits / sample
  - 2 channels
- Stats
  - 10s = 501 KB
  - 400 kbps
  - FLAC loseless



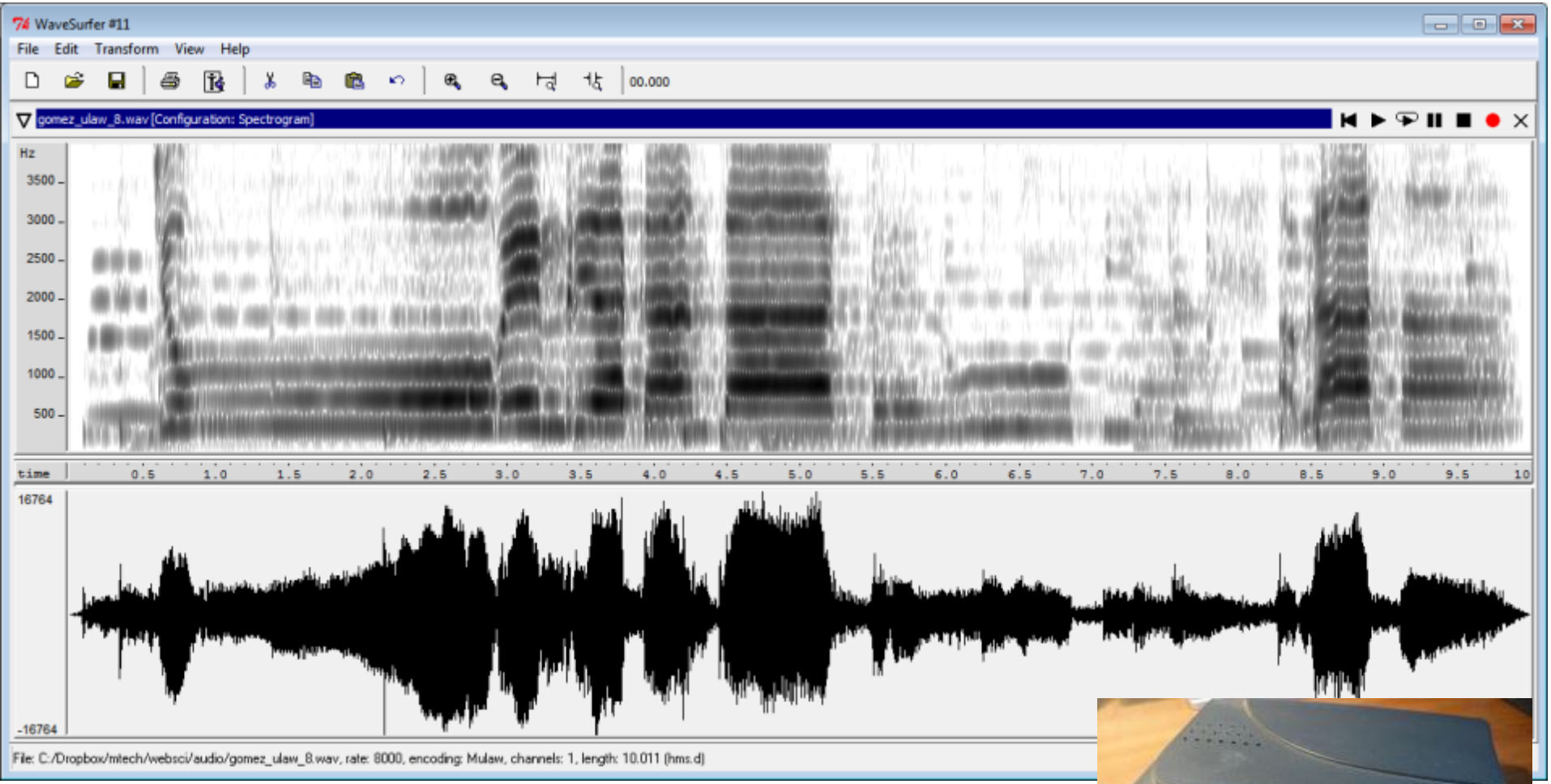
- 16 kHz sampling rate
  - 16 kHz sampling
  - 16 bits / sample
  - 2 channels
- Stats
  - 10s = 378 KB
  - 303 kbps
  - FLAC loseless



- 11 kHz sampling rate
  - 11 kHz sampling
  - 16 bits / sample
  - 2 channels
- Stats
  - 10s = 279 KB
  - 224 kbps
  - FLAC loseless



- 8 kHz sampling rate
  - 8 kHz sampling
  - 16 bits / sample
  - 2 channels
- Stats
  - 10s = 279 KB
  - 171 kbps
  - FLAC loseless



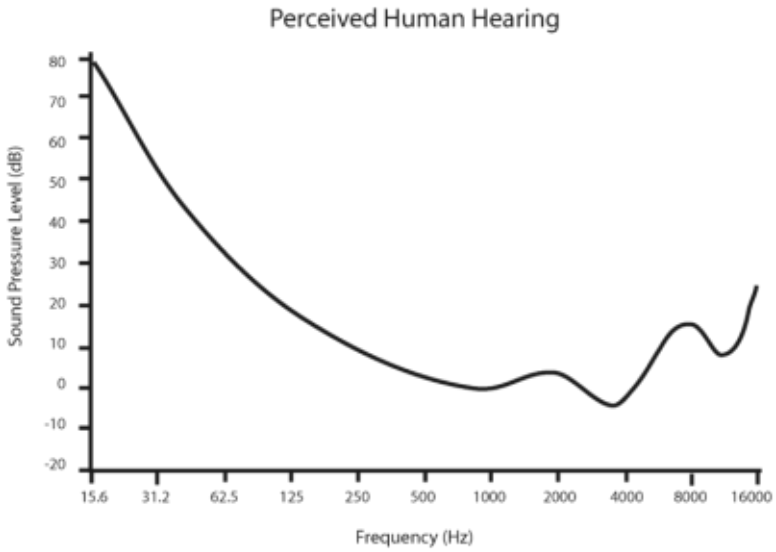
- 8 kHz sampling rate
  - 8 kHz sampling
  - 8 bits / sample
  - mono, µ-Law
- Stats
  - 10s = 80 KB
  - 64 kbps
  - Works on our 56K modem!
  - WAV

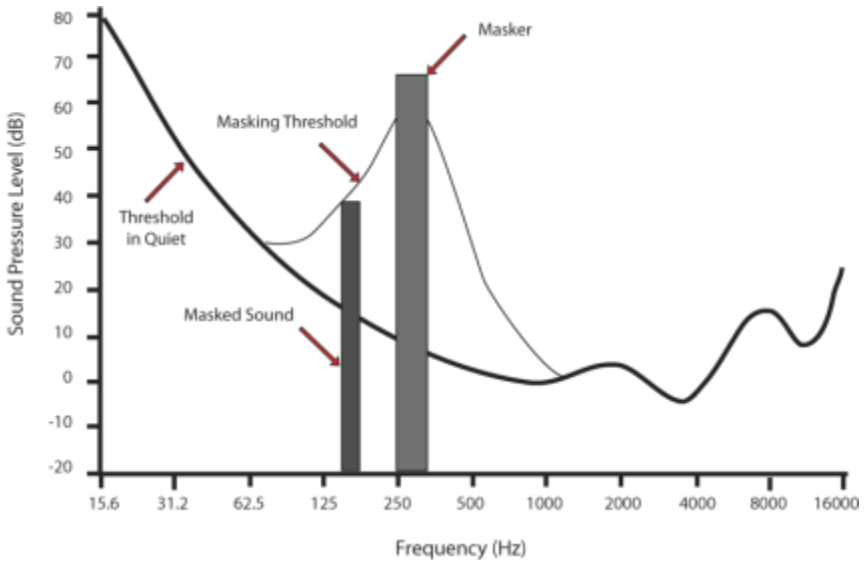
MPEG

- Motion Picture Experts Group (MPEG)
  - Formed to set audio/video compression standards
- MPEG 1
  - First phase started in 1988
  - Compress VHS quality video/audio to 1.5 Mbps
  - Layer 1, 2, 3 of increasing complexity
  - Audio layer 3 = MP3
- MPEG 2
  - Additional extensions
  - Advanced Audio Coding (AAC)
  - Greater sound quality at the same bit rate

MP3

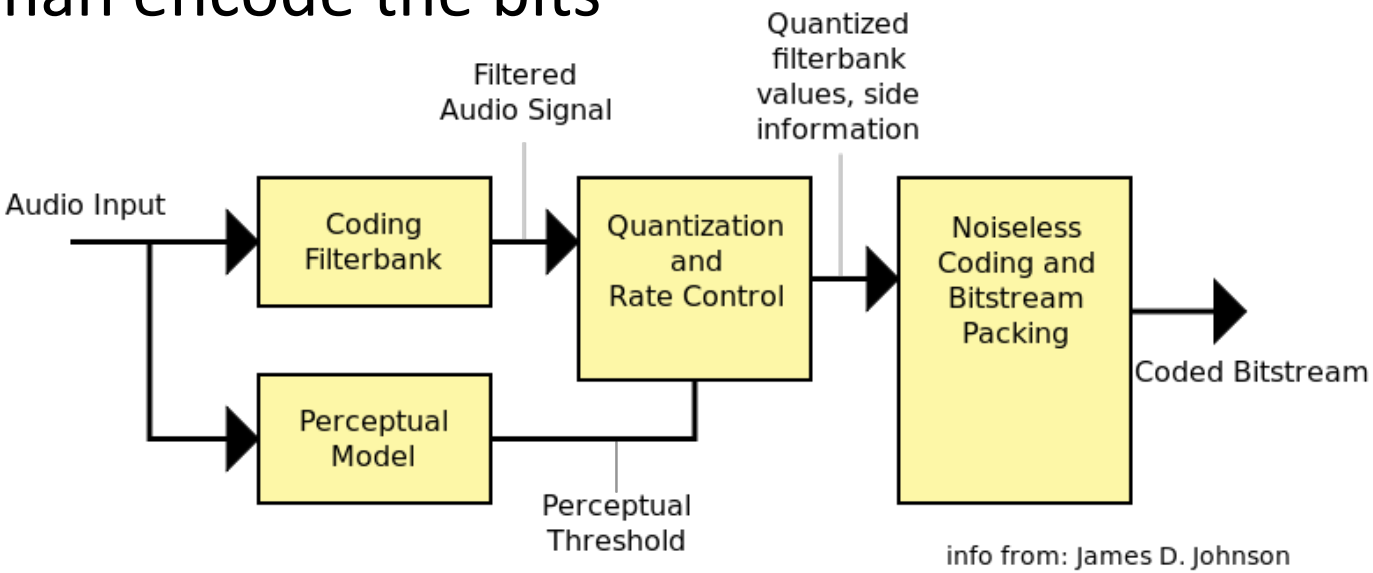
- Perceptual coding
  - Exploit flaws in the human auditory system
  - Psychoacoustics, encode signal so it sounds the same even though you've dropped information
    - Frequency masking, loud sound masks nearby weak one
    - Temporal masking, sudden sound make sounds inaudible slightly before (20 ms) and after (100 ms)



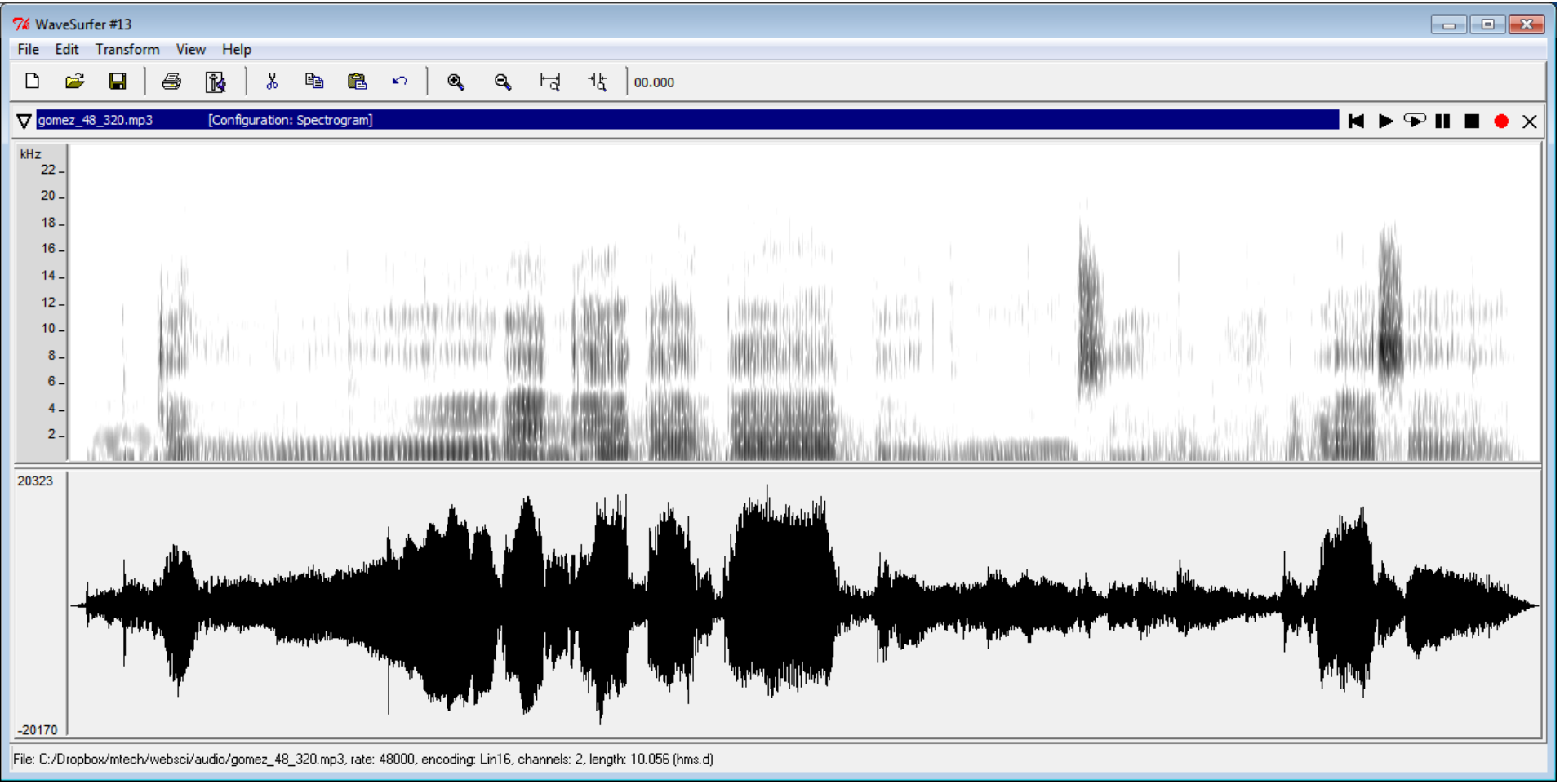


MP3

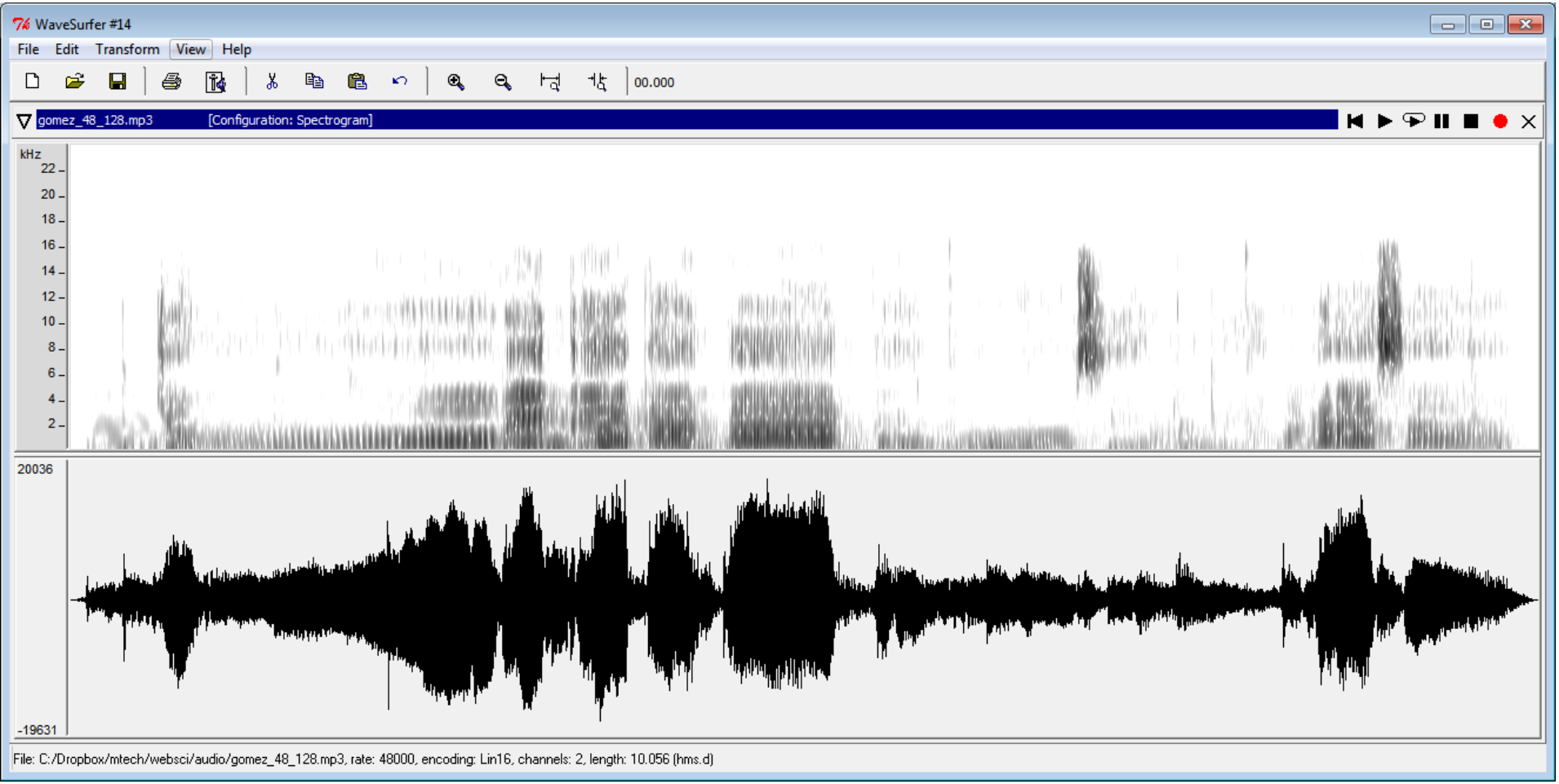
- Perceptual audio coding
  - Process audio in small batches
  - Pass through digital filters to get frequency bands
  - Psychoacoustic model determines masked freqs
  - Available bit budget divides among bands
    - More bits to bands with more spectral power
  - Huffman encode the bits



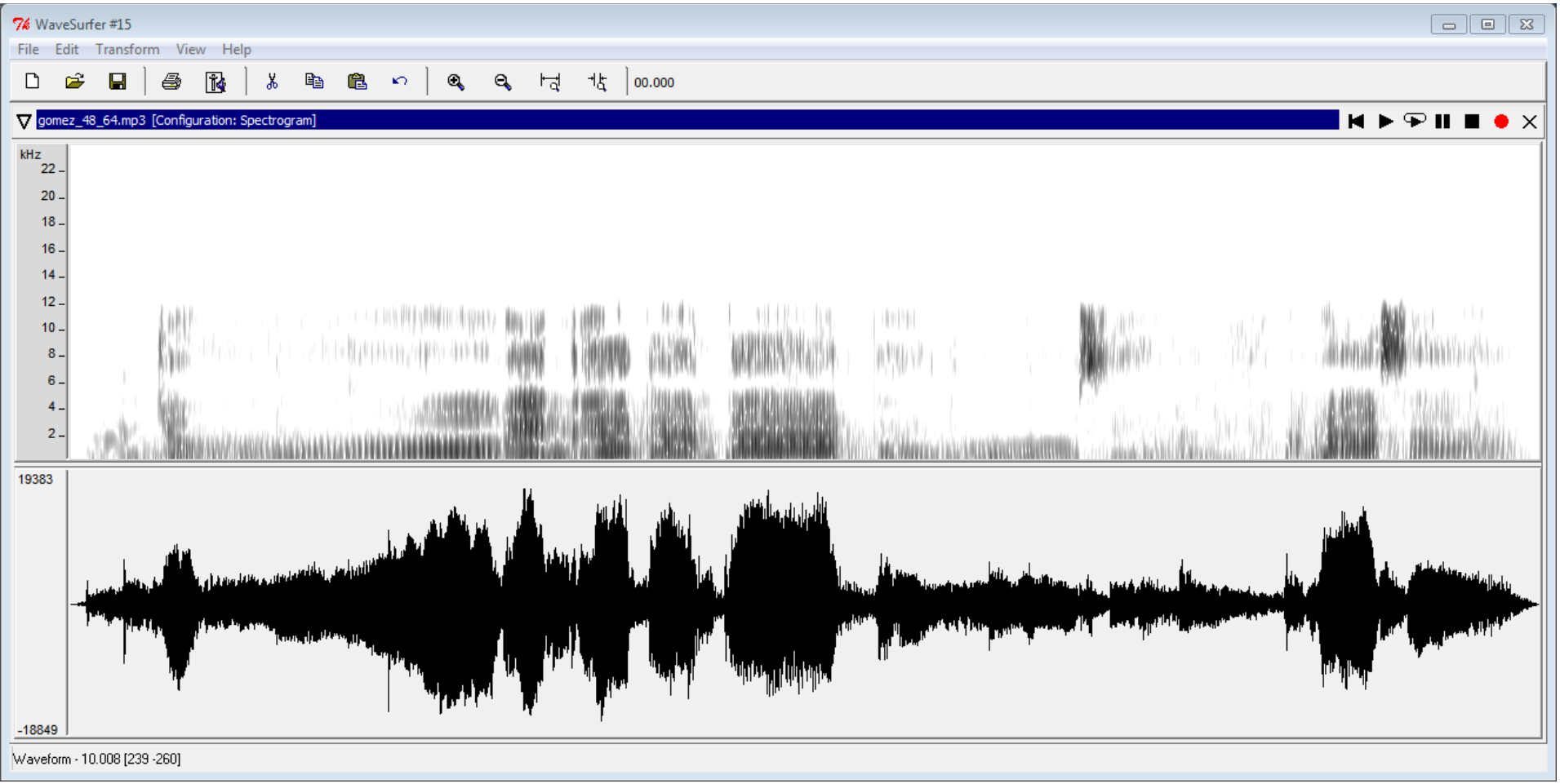
info from: James D. Johnson



- MP3
  - 48 kHz sampling
  - 320 kbps
  - 2 channels
- Stats
  - 10s = 402 KB
  - 322 Kbps
  - MPEG-1 audio layer 3



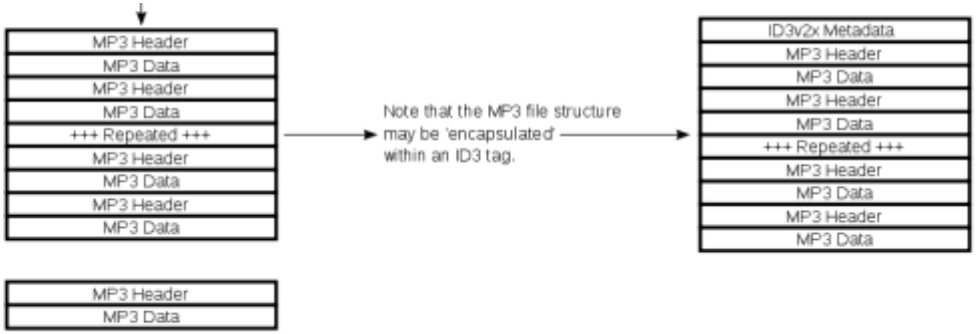
- MP3
  - 48 kHz sampling
  - 128 kbps
  - 2 channels
- Stats
  - 10s = 161 KB
  - 129 Kbps
  - MPEG-1 audio layer 3



- MP3
  - 48 kHz sampling
  - 64 kbps
  - 2 channels
- Stats
  - 10s = 81 KB
  - 65 Kbps
  - MPEG-1 audio layer 3

MP3 format

- Mandatory header with every frame
  - Every 24ms at 48 kHz sampling rate
  - You can drop into a live stream at any point



FFFBA040 Colour-coding shows binary bit mapping to hex values below

Bits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Binary	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Hex	F			F			F							B			A				0		0				4				0	
Meaning	MP3 Sync Word												Version	Layer		Error Protection	Bit Rate				Frequency		Pad. Bit	Priv. Bit	Mode		Mode Extension (Used With Joint Stereo)		Copy	Original	Emphasis	
Value	Sync Word												1 = MPEG	01 = Layer 3		1 = No	1010 = 160				00 = 44100 Hz		0 = Frame is not padded	Unknown	01 = Joint Stereo		0 = Intensity Stereo Off	0 = MS Stereo Off	0 = Not Copy-righted	0 = Copy Of Original Media	00 = None	

Audio file sizes

```
04/29/2012  04:41 PM         5,766,528 gomez_24_96.wav
04/29/2012  03:48 PM         3,411,865 gomez_24_96.flac

04/29/2012  06:43 PM           402,499 gomez_48_320.mp3
04/29/2012  06:49 PM           241,603 gomez_48_192.mp3
04/29/2012  07:12 PM           161,539 gomez_24_128.mp3
04/29/2012  07:11 PM           161,173 gomez_44_128.mp3
04/29/2012  06:50 PM           161,155 gomez_48_128.mp3
04/29/2012  06:51 PM           120,931 gomez_48_96.mp3
04/29/2012  06:53 PM            80,707 gomez_48_64.mp3
04/29/2012  06:53 PM            40,483 gomez_48_32.mp3
04/29/2012  06:54 PM            10,483 gomez_8_8.mp3
```

JPEG

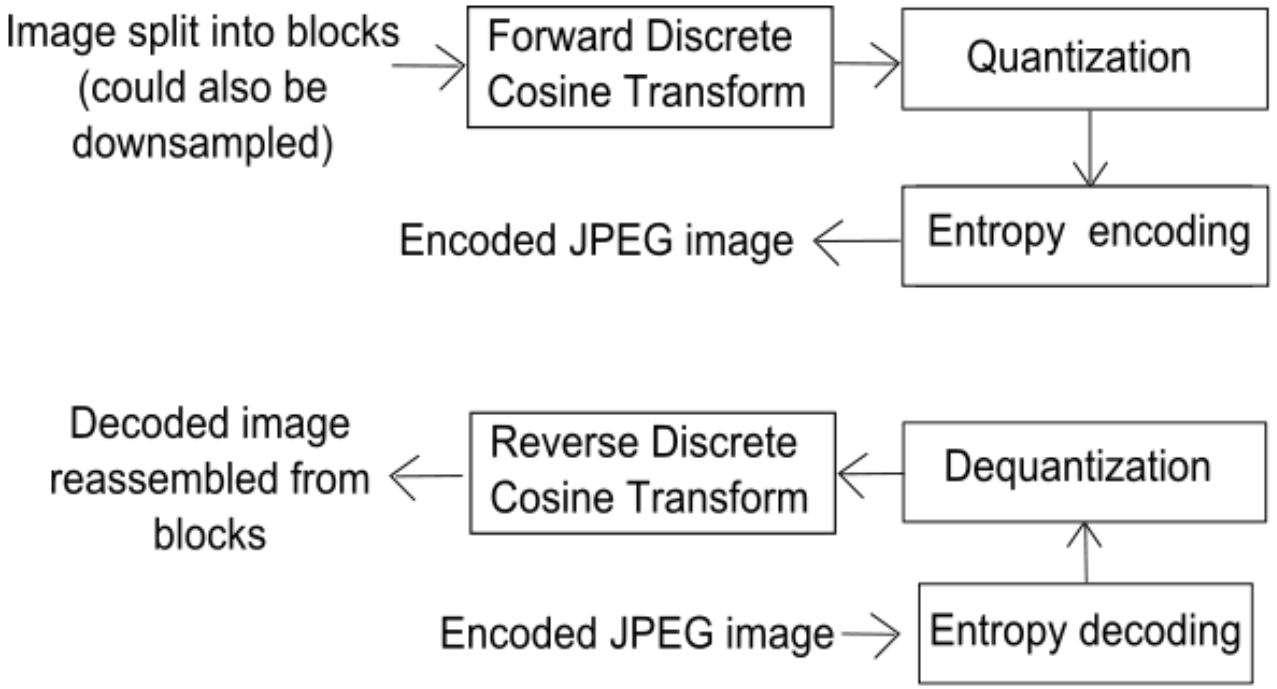
- Joint Photographic Experts Group (JPEG)
  - Compressing continuous-tone still pictures
    - e.g. photos, paintings
  - Not good for sharp changes in color
    - e.g. line drawings, text
  - Not good for repeated edits
  - Inherently a lossy process
    - Quality level 0 (low) to 100 (high)

Lossless image, 1920x1280 = 13.4MB

JPEG file sizes

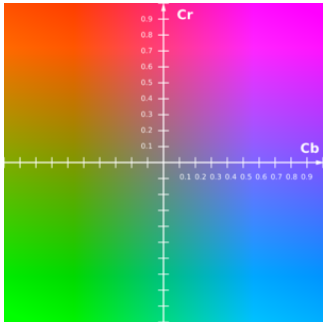
```
04/29/2012  08:09 PM        13,454,982 bike.tif

04/29/2012  08:11 PM         2,617,520 bike_q100.jpg
04/29/2012  08:12 PM           736,695 bike_q90.jpg
04/29/2012  08:12 PM           431,162 bike_q80.jpg
04/29/2012  08:13 PM           321,685 bike_q70.jpg
04/29/2012  08:14 PM           260,027 bike_q60.jpg
04/29/2012  08:14 PM           222,118 bike_q50.jpg
04/29/2012  08:25 PM           196,832 bike_q40.jpg
04/29/2012  08:25 PM           177,614 bike_q30.jpg
04/29/2012  08:26 PM           162,819 bike_q20.jpg
04/29/2012  08:26 PM           151,471 bike_q10.jpg
04/29/2012  08:26 PM           141,793 bike_q0.jpg
```

4-step process

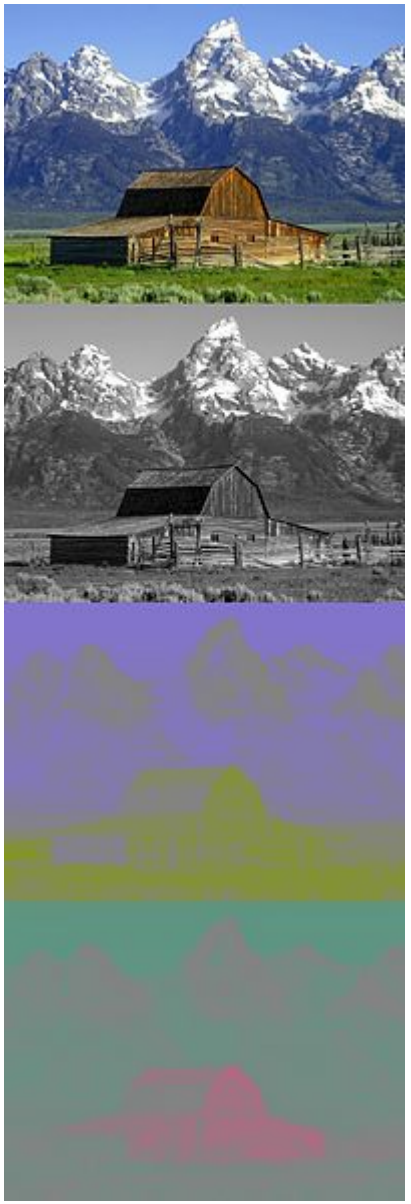


Step 1: JPEG compression

- Convert RGB colors to YCbCr
  - `Y  =  16 + 0.26R + 0.50G + 0.09B`
  - `Cb = 128 + 0.15R - 0.29G - 0.44B`
  - `Cr = 128 + 0.44R - 0.37G + 0.07B`
  - More info in luminance channel (Y)
- Separate channels into matrices
  - Assuming image is 640 x 480:
    - Reduce Cb and Cr to 320 x 240 by averaging square blocks of 4 pixels
    - Split matrices into 8 x 8 blocks
    - Subtract 128 from every element
  - Lossy, but hard to notice



Orig

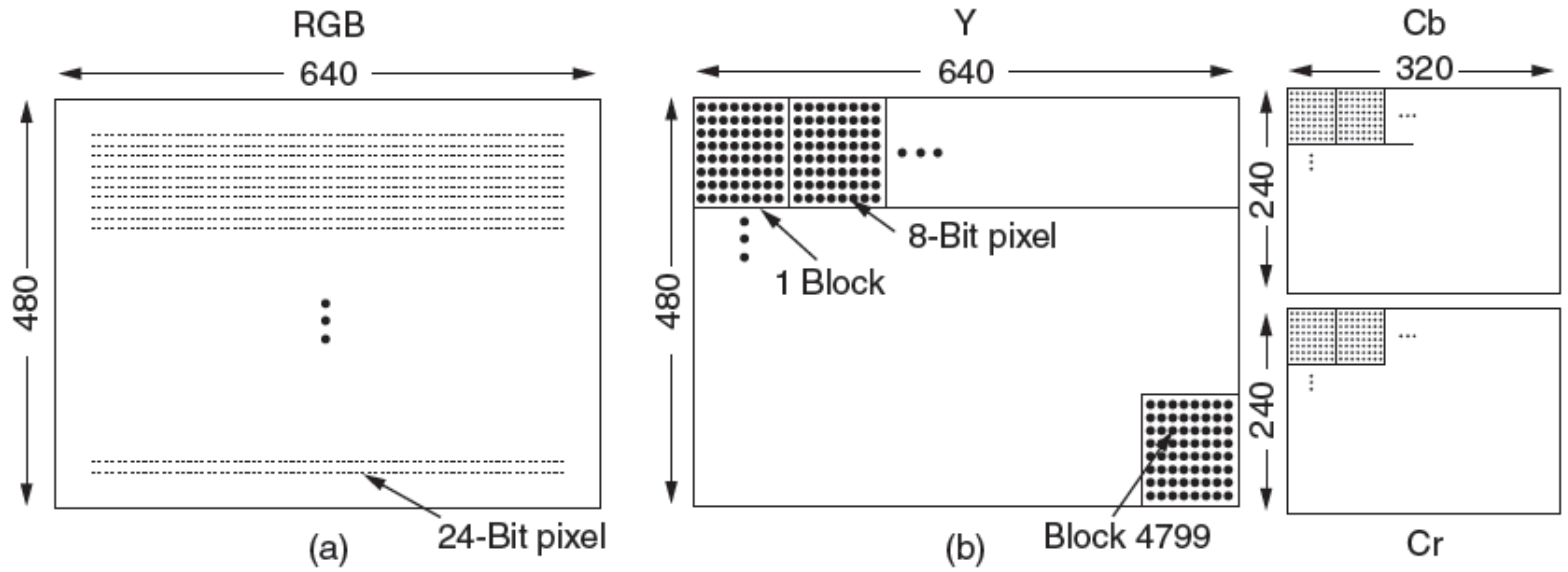


Y

Cb

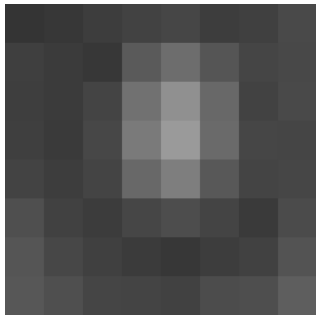
Cr

Step 2: JPEG compression



- Discrete Cosine Transformation (DCT)
  - Applied to each 8 x 8 block separately
  - Output is an 8 x 8 matrix of real numbers
  - DCT (0, 0) is average value of the block
  - Values typically decay rapidly away from (0, 0)
  - DCT not itself lossy (given sufficient precision)

$$\begin{bmatrix} 52 & 55 & 61 & 66 & 70 & 61 & 64 & 73 \\ 63 & 59 & 55 & 90 & 109 & 85 & 69 & 72 \\ 62 & 59 & 68 & 113 & 144 & 104 & 66 & 73 \\ 63 & 58 & 71 & 122 & 154 & 106 & 70 & 69 \\ 67 & 61 & 68 & 104 & 126 & 88 & 68 & 70 \\ 79 & 65 & 60 & 70 & 77 & 68 & 58 & 75 \\ 85 & 71 & 64 & 59 & 55 & 61 & 65 & 83 \\ 87 & 79 & 69 & 68 & 65 & 76 & 78 & 94 \end{bmatrix}.$$



$$DCT(i,j) = \frac{1}{\sqrt{2N}} C(i)C(j) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} pixel(x,y)$$
$$\times \cos\left[\frac{(2x+1)i\pi}{2N}\right] \cos\left[\frac{(2y+1)j\pi}{2N}\right]$$

$$pixel(x,y) = \frac{1}{\sqrt{2N}} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} C(i)C(j)DCT(i,j)$$
$$\times \cos\left[\frac{(2x+1)i\pi}{2N}\right] \cos\left[\frac{(2y+1)j\pi}{2N}\right]$$

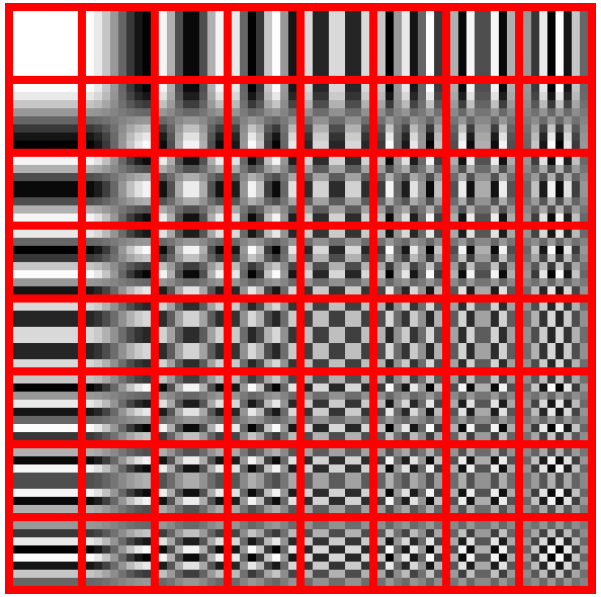
$$C(x) = \begin{cases} \frac{1}{\sqrt{2}} & \text{if } x = 0 \\ 1 & \text{if } x > 0 \end{cases}$$

$$g = \begin{bmatrix} -76 & -73 & -67 & -62 & -58 & -67 & -64 & -55 \\ -65 & -69 & -73 & -38 & -19 & -43 & -59 & -56 \\ -66 & -69 & -60 & -15 & 16 & -24 & -62 & -55 \\ -65 & -70 & -57 & -6 & 26 & -22 & -58 & -59 \\ -61 & -67 & -60 & -24 & -2 & -40 & -60 & -58 \\ -49 & -63 & -68 & -58 & -51 & -60 & -70 & -53 \\ -43 & -57 & -64 & -69 & -73 & -67 & -63 & -45 \\ -41 & -49 & -59 & -60 & -63 & -52 & -50 & -34 \end{bmatrix}$$

($x \longrightarrow$, $y \downarrow$)

$$G = \begin{bmatrix} -415.38 & -30.19 & -61.20 & 27.24 & 56.13 & -20.10 & -2.39 & 0.46 \\ 4.47 & -21.86 & -60.76 & 10.25 & 13.15 & -7.09 & -8.54 & 4.88 \\ -46.83 & 7.37 & 77.13 & -24.56 & -28.91 & 9.93 & 5.42 & -5.65 \\ -48.53 & 12.07 & 34.10 & -14.76 & -10.24 & 6.30 & 1.83 & 1.95 \\ 12.12 & -6.55 & -13.20 & -3.95 & -1.88 & 1.75 & -2.79 & 3.14 \\ -7.73 & 2.91 & 2.38 & -5.94 & -2.38 & 0.94 & 4.30 & 1.85 \\ -1.03 & 0.18 & 0.42 & -2.42 & -0.88 & -3.02 & 4.12 & -0.66 \\ -0.17 & 0.14 & -1.07 & -4.19 & -1.17 & -0.10 & 0.50 & 1.68 \end{bmatrix}$$

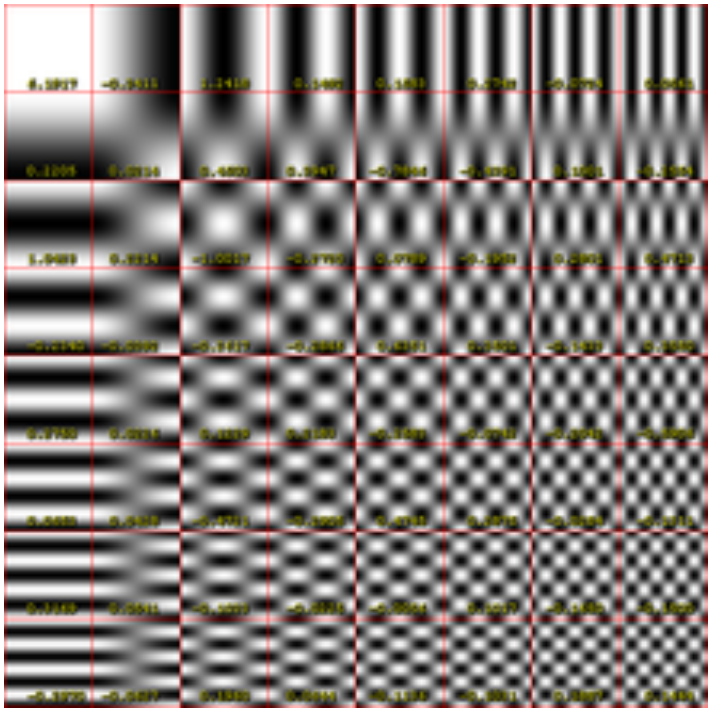
($u \longrightarrow$, $v \downarrow$)



8x8

A

$$\begin{bmatrix} 6.1917 & -0.3411 & 1.2418 & 0.1492 & 0.1583 & 0.2742 & -0.0724 & 0.0561 \\ 0.2205 & 0.0214 & 0.4503 & 0.3947 & -0.7846 & -0.4391 & 0.1001 & -0.2554 \\ 1.0423 & 0.2214 & -1.0017 & -0.2720 & 0.0789 & -0.1952 & 0.2801 & 0.4713 \\ -0.2340 & -0.0392 & -0.2617 & -0.2866 & 0.6351 & 0.3501 & -0.1433 & 0.3550 \\ 0.2750 & 0.0226 & 0.1229 & 0.2183 & -0.2583 & -0.0742 & -0.2042 & -0.5906 \\ 0.0653 & 0.0428 & -0.4721 & -0.2905 & 0.4745 & 0.2875 & -0.0284 & -0.1311 \\ 0.3169 & 0.0541 & -0.1033 & -0.0225 & -0.0056 & 0.1017 & -0.1650 & -0.1500 \\ -0.2970 & -0.0627 & 0.1960 & 0.0644 & -0.1136 & -0.1031 & 0.1887 & 0.1444 \end{bmatrix}$$



Step 3: JPEG compression

- Quantization
  - Divide the DCT coefficients by a table of weights
    - Different tables for different JPEG quality levels
  - Round the result

$$G = \begin{bmatrix} -415.38 & -30.19 & -61.20 & 27.24 & 56.13 & -20.10 & -2.39 & 0.46 \\ 4.47 & -21.86 & -60.76 & 10.25 & 13.15 & -7.09 & -8.54 & 4.88 \\ -46.83 & 7.37 & 77.13 & -24.56 & -28.91 & 9.93 & 5.42 & -5.65 \\ -48.53 & 12.07 & 34.10 & -14.76 & -10.24 & 6.30 & 1.83 & 1.95 \\ 12.12 & -6.55 & -13.20 & -3.95 & -1.88 & 1.75 & -2.79 & 3.14 \\ -7.73 & 2.91 & 2.38 & -5.94 & -2.38 & 0.94 & 4.30 & 1.85 \\ -1.03 & 0.18 & 0.42 & -2.42 & -0.88 & -3.02 & 4.12 & -0.66 \\ -0.17 & 0.14 & -1.07 & -4.19 & -1.17 & -0.10 & 0.50 & 1.68 \end{bmatrix}$$

($u \rightarrow$, $v \downarrow$)

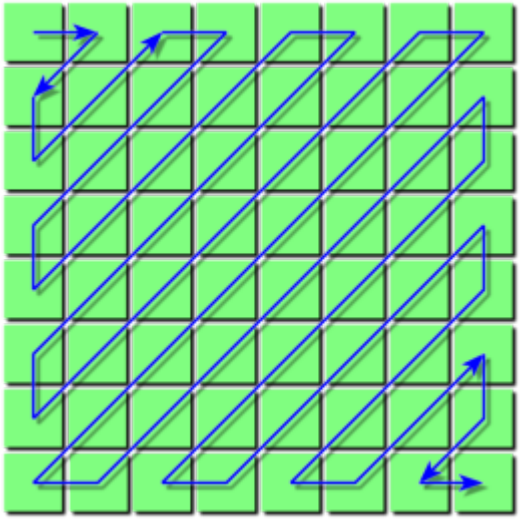
$$Q = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

$$B = \begin{bmatrix} -26 & -3 & -6 & 2 & 2 & -1 & 0 & 0 \\ 0 & -2 & -4 & 1 & 1 & 0 & 0 & 0 \\ -3 & 1 & 5 & -1 & -1 & 0 & 0 & 0 \\ -3 & 1 & 2 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Step 4: JPEG compression

- Encoding the elements
  - Zig-zag pattern to try and get lots of 0's in a row
    - Run-length encoding (RLE)
  - Huffman encode the result

$$B = \begin{bmatrix} -26 & -3 & -6 & 2 & 2 & -1 & 0 & 0 \\ 0 & -2 & -4 & 1 & 1 & 0 & 0 & 0 \\ -3 & 1 & 5 & -1 & -1 & 0 & 0 & 0 \\ -3 & 1 & 2 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$



Summary

- MP3
  - Most prevalent lossy audio format
  - Psychoacoustic model
    - Throw away things from audio you can't hear anyway
- JPEG
  - Most prevalent lossy still image format
  - Change colorspace and downsample
  - Lossy:
    - Ignore less important changes in 8 x 8 blocks
    - Controlled quality via quantization tables
  - Lossless compress using RLE and Huffman