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Data Compression

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Compression

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The idea

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- Say we have to send a 1K x 1K pixel, 24-bit-color image = 3MB.
- As-is, the transmission delay for a 64Kbps link will be ~7min.
- If we can compress it so that it is 10 times smaller (“10:1 compression ratio”), it will be 300KB, which takes ~42sec to send.

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Types of compression algorithms

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- Lossless
  - The original data can be perfectly recovered by decompression.
  - Needed for text files, code, executables…
- Lossy
  - The original data cannot be exactly recovered.
  - OK for photos, video, voice…

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Lossless algorithms

Run-Length Encoding

- The idea: Replace runs of a symbol with one copy of the symbol + the count.
- Example:
  - "AAAABCCCDD" (10 symbols) → A4BC3D2 (7 symbols)
- Good where there are long runs of a symbol (faxes, .bmp images…)
- Typical Performance:
  - For scanned text, 8:1 compression is common

Huffman encoding

- The idea: Instead of using the same number of bits for every symbol in a string, we encode each symbol with a number of bits that is inversely proportional to the symbol's frequency in the string.
- Example:

1000-symbol string
With 4 symbols

Frequency:

A	30%
B	50%
C	15%
D	5%

Normal encoding

A	00
B	01
C	10
D	11
	—
Total bits	2000

Huffman encoding

A	01	2x300 = 600 bits
B	0	1x500 = 500 bits
C	011	3x150 = 450 bits
D	0111	4x50 = 200 bits
		________
Total bits		1750

Performance varies with string and frequencies.
Not good for even distribution of symbols

Pulse-Code Modulation (Differential)

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- The idea: Symbols are encoded based on their "distance" from a reference symbol.

- Example:
  - ASCII Source string = "AAABCCDDEGF" (88 bits)
  - We choose to encode symbols with 8 bits and distances with 2 bits (when the distance becomes greater than 3, choose a new base symbol).
  - Encoded string = "A0012233E21"
    Number of bits = 82222222822 (35 bits)

- Effective when adjacent symbols are "similar" (e.g, imagery)

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Dictionary methods (Lempel-Ziv) - 1

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- The idea: Build a dictionary of the "phrases" in the source. Assign each phrase a number and xmit the numbers. (phrases can be anything – fixed # characters, words in a language…)

- Note: you either must have a standard dictionary, or you must send the dictionary along with the encoded string

- Effective when the number of phrases is small relative to the length of the string.

- Used in Unix "Compress" and Windows "Zip"

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Dictionary methods (Lempel-Ziv) - 2

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Example:

"one small step for man one giant leap for mankind" (392 bits in ASCII)

Dictionary	
one_	000
small_	001
step_	010
for_	011
man_	100
giant_	101
leap_	110
mankind_	111

Encoded form: 000 001 010 011 100 000 101 110 011 111 → 30 bits

If you must send the dictionary, you have an additional 42 characters → 336 bits

So, for standard dictionary = 30 bits, ~ 13:1 compression
for non-standard dictionary = 366 bits, ~ 1.1:1 compression

Graphical Interchange Format (GIF)

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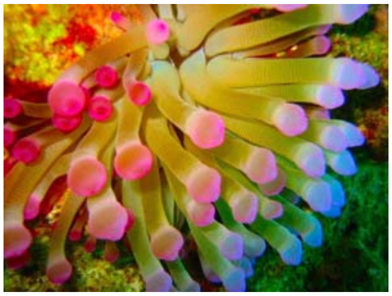
- Used for image compression – only lossless when original image has fewer than 256 colors
- Algorithm:
  1. If necessary, reduce # colors to 256 (8 bits per pixel)
  2. Run LZ on the result
- Works best for images that have repeating patterns (e.g, photo of a picket fence or tiled floor).
- Typical: 4:1 – 10:1 compression ratio

GIF example (lossy)



Original JPEG (24-bit color)

GIF (8-bit color)

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Lossy algorithms

JPEG

- JPEG = ISO “Joint Photographic Experts Group”
- Algorithm:
  1. Do a spectral analysis of each 8x8 pixel block (lossless)
  2. Quantize (round) the spectral results (lossy)
  3. Run RLE and Huffman on the result (lossless)
- User controls quality of reconstructed image by choosing how much rounding is done in step 2 → trade quality for size
- Typical:
  - HQ: 10:1 → 20:1
  - MQ: 30:1 → 50:1
  - LQ: 60:1 → 100:1

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JPEG example

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High Quality
34KB

Medium Quality
6KB

Low Quality
2KB

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Video streams

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- Uncompressed VCR-class video
  - 352 x 240 pixels, 24 bit color, 25 frames/sec
  - ~51Mbps
- Uncompressed Broadcast-quality standard video (NTSC)
  - 720 x 480 pixels
  - ~207Mbps
- Uncompressed HDTV-quality video
  - 1920 x 1080 pixels
  - ~1.2Gbps
- Significant compression needed to carry these at reasonable bandwidths

MPEG

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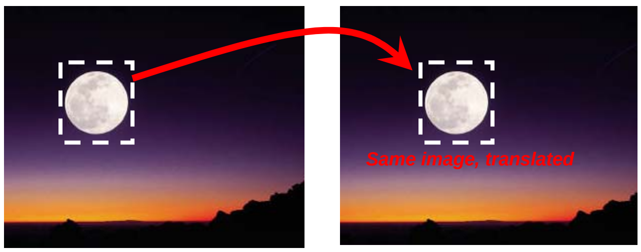
- MPEG = Motion Picture Experts Group
- Standards:
  - MPEG-1: VCR-quality video, 1.2Mbps
  - MPEG-2: HDTV-quality video, 4-8Mbps
  - MPEG-3 (“MP3”): CD-quality audio, 96-128Kbps
  - MPEG-4: MPEG-2 + VRML, DRM, Interactive video

MPEG video concepts

- Based on JPEG
  - We could just do a JPEG image of each frame of video
  - But we can improve on that by taking advantage of common features across frames



There is generally A significant amount of repeated Sub-images from one frame to another

MPEG-2 Approach

- Each frame in the video stream are encoded as one of the following types:
  - I-frame:
    - A JPEG-encoded still image
    - I-frames are included periodically as a reference
  - P-frame:
    - An encoding of the differences between the last frame and this one
    - Image broken up into 16x16 subimages that are similar in both frames, maybe in different places ("macroblocks")
    - Differences expressed in terms of movement, transformation of macroblocks.
  - B-frame:
    - Like a P-frame, but based on either previous or next frame

Audio streams

- Uncompressed POTS-quality sound
  - 4Khz Bandwidth
  - 8bit sample / 125usec → 64Kbps
- Uncompressed CD-quality audio:
  - 44Khz Bandwidth
  - 16-bit sample / 23usec x 2 channels for stereo → 1.4Mbps

MPEG-3 audio compression

- The idea: don't transmit the sounds people don't hear
  - Strong sounds at one frequency tend to mask softer sounds at nearby frequencies – do not transmit the masked sounds
- Algorithm:
  - For every 26msec, measure power in 32 frequency bands
  - Allocate higher bps to bands with most power, less bps to bands with less power
  - Huffman code the allocated bits
- Performance:
  - CD quality at 128Kbps – 12:1 compression