Multimedia

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Topics

- **Overview**
- **Encoding & Compression**
  - Audio, still images, video
  - JPEG, MPEG
- **Storage & Transmission**
  - Rates & Capacities
- **Processing**
  - Architectural Extensions
  - Intel MMX

What is (Digital) Multimedia?

- ***Integration of two or more media using computer technology***
  - E.g., audio, video

Reproductions

- **Still or video images, recorded music or speech**

Synthesized

- **Animations, MIDI recordings, virtual reality**

Major Driver of Computer Technology

- **High market demand**
- **High computation, communication, and storage requirements**
  - Real time processing required
  - Requirements scale rapidly with increased quality
    - » E.g., quadratically with image resolution

Glossary

Storage Sizes

- KB = 1024 bytes   MB = 1,048,576 bytes   GB = 1,073,741,824 bytes

Acronym Interpretation

• NTSC	U.S. / Japan television standard
• JPEG	Still image compression & encoding format
• MPEG	Moving image compressing & encoding format
• CD / CDROM	Based on compact disk technology
• DVD	Digital Video Disk

Complexity Example

"NTSC" Quality Computer Display

- 640 X 480 pixel image
- 3 bytes per pixel (Red, Green, Blue)
- 30 Frames per Second

Bandwidth

- 26.4 MB/second
- Corresponds to 180X CDROM
- Exceeds bandwidth of almost all disk drives

Storage

- CDROM would hold 25 seconds worth
- 30 minutes would require 46.3 GB

Observation

- Some form of compression required

Lossless Data Compression

Principle

- Reconstructed = Original
- Exploit property that some bit sequences more common than others
- Time (compress/decompress) – Space (data size) tradeoff

Lempel-Ziv encoding

- Build up table of frequenctly occurring sequences
- E.g., Unix compress (.Z), DOS Gzip (.zip)
- Achieve compression ratio ~ 2:1 (text, code, executables)

Huffman Encoding

- Assign shorter codes to most frequent symbols

Lossy Compression

- **Reconstructed data approximates original**
- **Want compression ratios ≥ 10:1**

Tradeoffs

- **Time vs. space**
- **Space vs. quality**
  - Greater compression possible if looser approximation allowed

Application Dependent

- **Exploit characteristics of human perception**
- **Examples**
  - Eye’s sensitivity to color variations less than to brightness

Digitizing Analog Waveforms

Sampling

- **Measure signal value at regular time intervals**
- **dt = 1/ Sampling frequency**
- **Nyquist Theorem**
  - Must sample at ≥ 2 * highest frequency signal component
  - Otherwise get “aliasing” between low and high frequency values

Analog to Digital Conversion

- **Convert each sample into k-bit value**
- **Limits dynamic range**
- **Low resolution gives “quantization error”**

Audio Encoding

Frequency Response

- **Humans can hear sounds ranging from around 5 Hz to 15 KHz**
- **Piano notes range from 15 Hz to 15KHz**
- **Telephone limits frequency range to between 300Hz & 3 KHz**

Dynamic Range

- **Humans can perceive sounds over 10 order of magnitude dynamic range**
- **100 Decibels**
  - Every 3 dB corresponds to doubling sound intensity

Compact Disk Recording

Parameters

- **44,100 samples per second**
  - Sufficient for frequency response of 22KHz
- **Each sample 16 bits**
  - 48 dB range
- **Two independent channels**
  - Stereo sound
  - Dolby surround-sound uses tricks to pack 5 sound channels + subwoofer effects

Bit Rate

- **44,100 samples/second X 2 channels X 2 bytes = 172 KB / second**

Capacity

- **74 Minutes maximum playing time**
- **747 MB total**

CD ROM Technology

Basis

- **Use technology developed for audio CDs**
- **Add extra 288 bytes of error correction for every 2048 bytes of data**
  - Cannot tolerate any errors in digital data, whereas OK for audio

Bit Rate

- **172 * 2048 / (288 + 2048) = 150 KB / second**
  - For 1X CDROM
  - *N* X CDROM gives bit rate of *N* * 150
  - E.g., 12X CDROM gives 1.76 MB / second

Capacity

- **74 Minutes * 150 KB / second * 60 seconds / minute = 650 MB**
- **Typically around 527 MB to reduce manufacturing cost**

Image Encoding & Compression

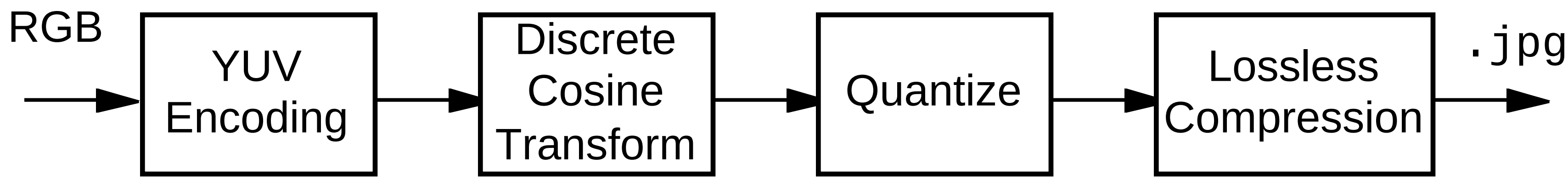
Computer-Generated Images

- **Limited number of colors (e.g., $\leq$ 256)**
- **Large monochrome regions**
- **Sharp boundaries between regions**
- **GIF encoding works well**
  - Lossless compression of 8-bit color images

Natural Scenes

- **Large number of colors (want 24-bit quality)**
- **Widely varying intensities and colors**
- **Boundaries not sharp**
- **Can eliminate details for which human perception is weak**
- **JPEG encoding works well**
  - Lossy compression based on spectral transforms
  - Can achieve from 10:1 to 20:1 compression with little loss in quality

JPEG Encoding Steps



Encoding

- **Convert to different color representation**
- **Typically get 2:1 compression**

Discrete Cosine Transform (DCT)

- **Transform 8 X 8 pixel blocks**

Quantize

- **Reduce precision of DCT coefficients**
- **Lossy step**

Lossless Compression

- **Express image in information in highly compressed form**

YUV Encoding

Computation

- **RGB numbers between 0 and 255**
- ***Luminance* Y encodes grayscale intensity between 0 and 255**
- ***Chrominance* U, V encode color information between –128 and +127**
  - Similar to Color (Hue) and Tint (Saturation) controls on color TV

Conversion

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- **Values saturate at ends of ranges**

Color Subsampling

- **Average U,V values over 2 X 2 blocks of pixels**
- **Human eye less sensitive to variations in color than in brightness**

Image Examples

- **Scanned from CMU catalog**
- **248 X 324 X 3B**
- **Moiré interference pattern caused by scanning digitized image**

Color Subsampling

- **2:1 Compression**
- **No visible effect**

Discrete Cosine Transform

Image Partitioning

- **Divide into 8 X 8 pixel blocks**
- **Express each block as weighted sum of cosines**
  - Similar to Fourier Transform

Transform Computation

F(u,v) = K(u,v) * Sum(i = 0,7) Sum(j = 0,7)

f(i,j) * cos ([2i+1] * u * π/16) * cos ([2j+1] * v * π /16)

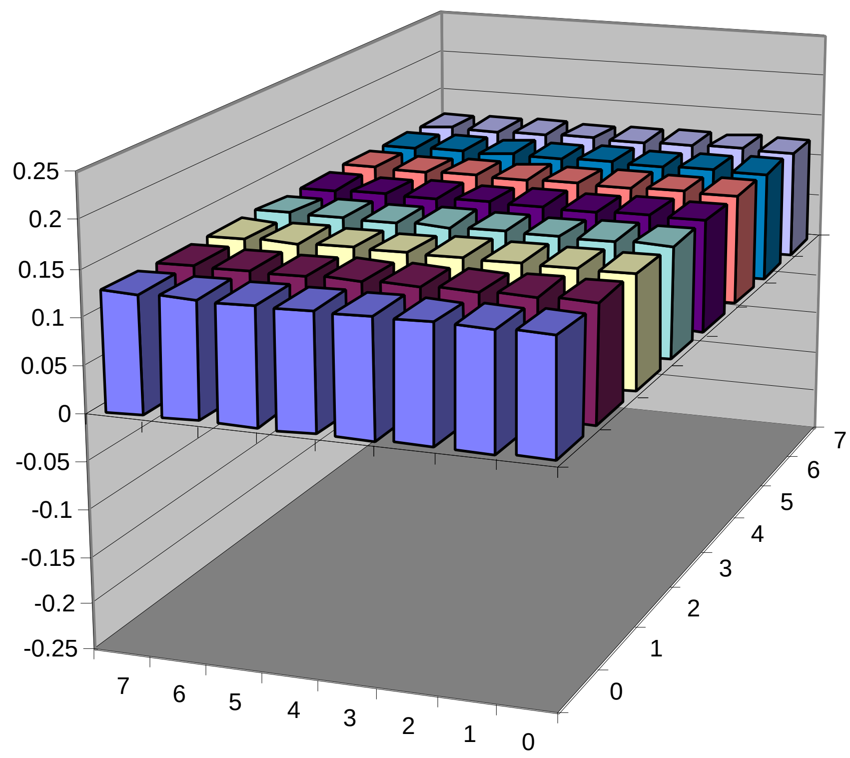
Inverse Transform

f(i,j) = Sum(u = 0,7) Sum(v = 0,7)

k(u,v) * F(u,v) * cos ([2i+1] * u * π/16) * cos ([2j+1] * v * π /16)

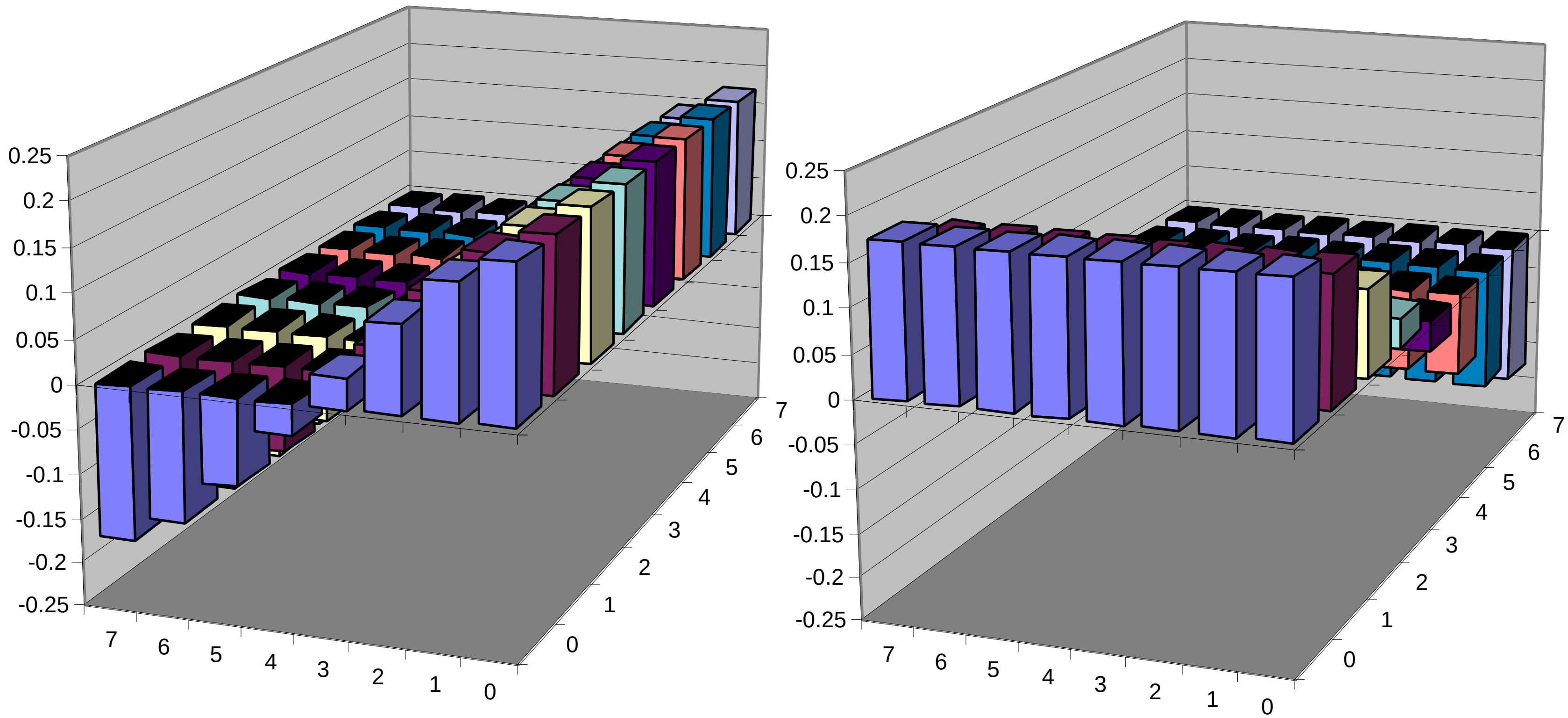
- **Expresses image as sum of discretized cosine waveforms**
  - Would be exact, except for roundoff and saturating values
- **Each waverform weighted by coefficient F(u,v)**
- **Low values of u, v correspond to slowly varying waveforms**

Inverse DCT of Selected Coefficients



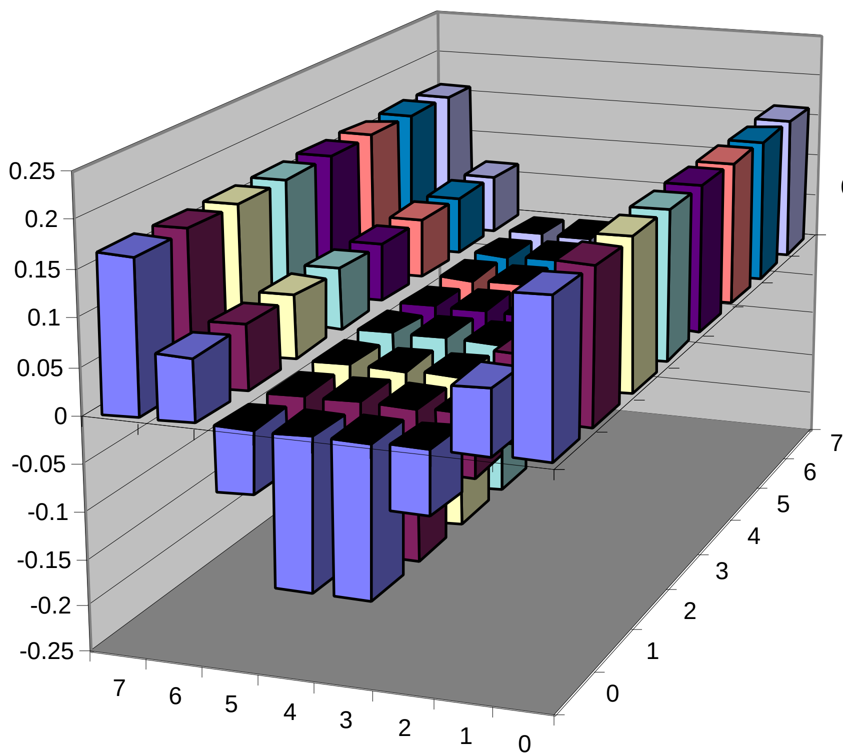
- **Coefficient (0, 0)**
  - i.e., F(0, 0) = 1, all others = 0
- **Characterizes overall average**

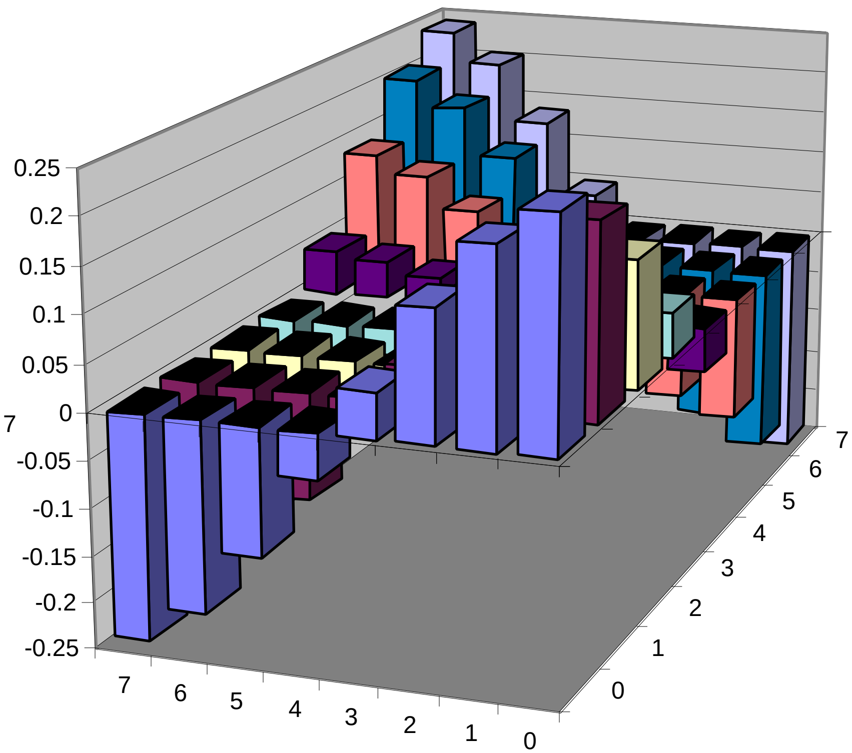
Inverse DCT of Selected Coefficients



- **Coefficients (1,0) and (0,1)**
- **Capture horizontal or vertical gradient**

Inverse DCT of Selected Coefficients

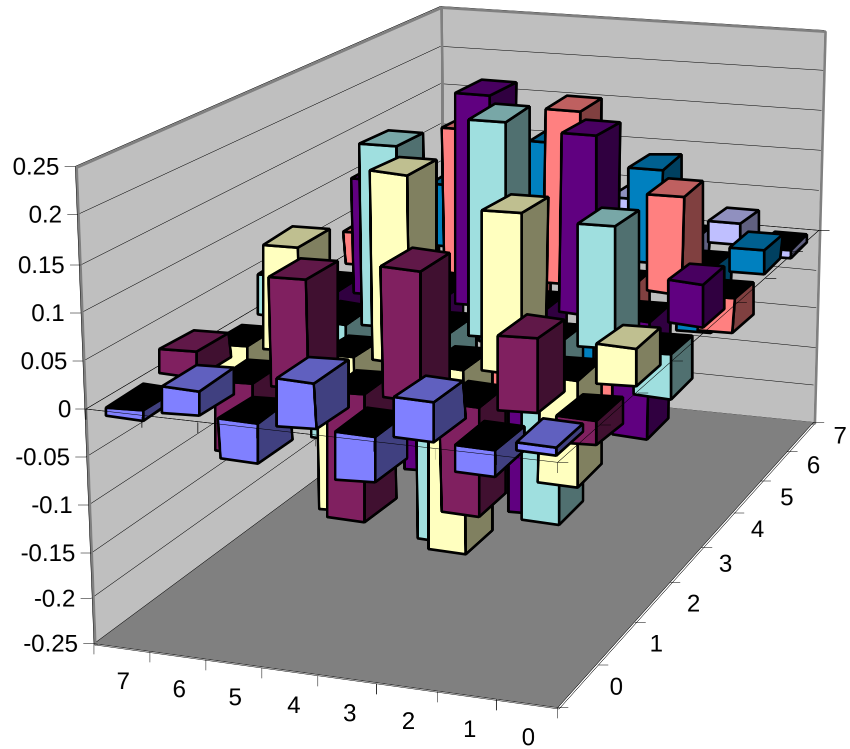




- **Coefficient (2,0)**
- **Captures vertical banding**

- **Coefficient (1,1)**
- **Captures diagonal variation**

Inverse DCT of Selected Coefficients



- **Coefficient (7,7)**
- **Captures high spatial variations**

Quantization

Quantization Coefficient Q(u,v) for each waveform (u,v)

- **Approximate F(u,v) as Q(u,v) * Round[F(u,v) / Q(u,v)]**
  - E.g., if Q is 2^k, just set low order k bits to 0
- **High value of Q gives coarser approximation**

Selecting Q's

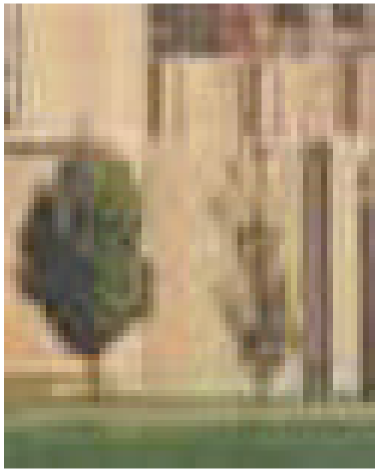
- **Increase to get greater compression**
  - Major source of loss in JPEG
- **Generally use Q's that increase with u and v**
  - High spatial frequencies not as important
  - Hope that many coefficients will be set to 0

JPEG Compression Examples

28:1 Compression

Original

Compressed



- **Quality still reasonable**
- **Some loss of fine detail**

JPEG Compression Examples

66:1

- **Quality drops dramatically as increase compression ratio**
- **Throws out color information first**

JPEG Compression Examples

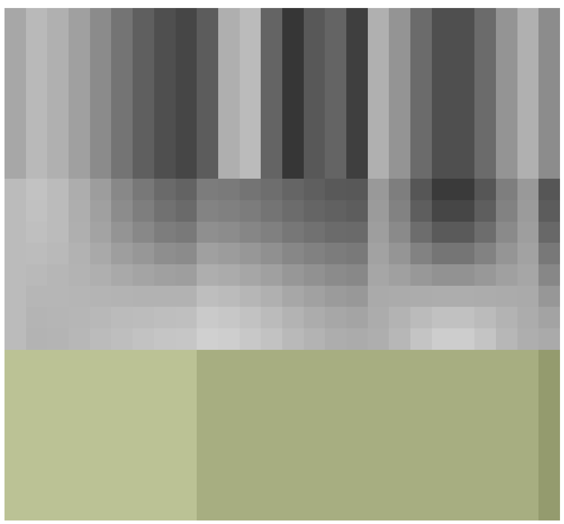
86:1

101:1

DCT Quantization Effects

Blow Up Sections of Low Quality Images

- **See 8 X 8 blocks**
- **Only low frequency coefficients for Y**
- **Extreme subsampling for U, V**
  - Single value for 16 X 8 pixels



MPEG Video Encoding

MPEG-1

- **Targeted to "VHS" quality video on CDROM**
  - 352 X 240 pixels
  - Display on computer screens
- **Two forms of lossy compression**
  - Spatial compression similar to JPEG
  - Temporal compression exploiting similarity between successive frames
    - » E.g., stationary background, panning

MPEG-2

- **Broader range of applications**
  - Including Digital Video Disk (DVD) players
- **Support for fancier features**
- **Aim for baseline of 720 X 480 pixels**

Baseline MPEG-1

Video Channel

- 352 X 240 pixels, with subsampling of chrominance to 176 X 120
- 30 frames per second
- 26:1 compression drops bit rate to 143 KB / second

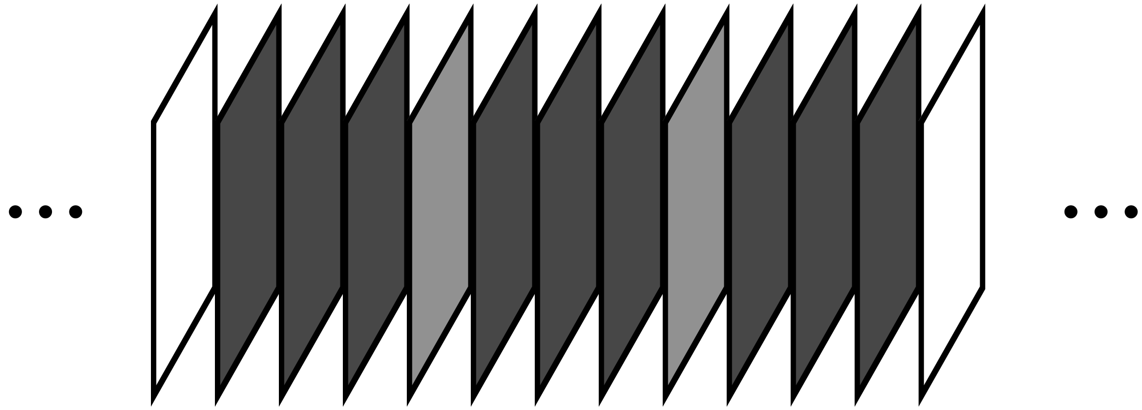
Audio

- Compress CD sound by 6:1
- Bit rate = 32 KB / second

Performance

- 175 KB / second matches performance of early CD ROM drives
- Store > 1 hour on CD
- Software-only decoders running on PC-class machines cannot decode fast enough
  - Typically limited to 8–10 FPS

MPEG Encoding

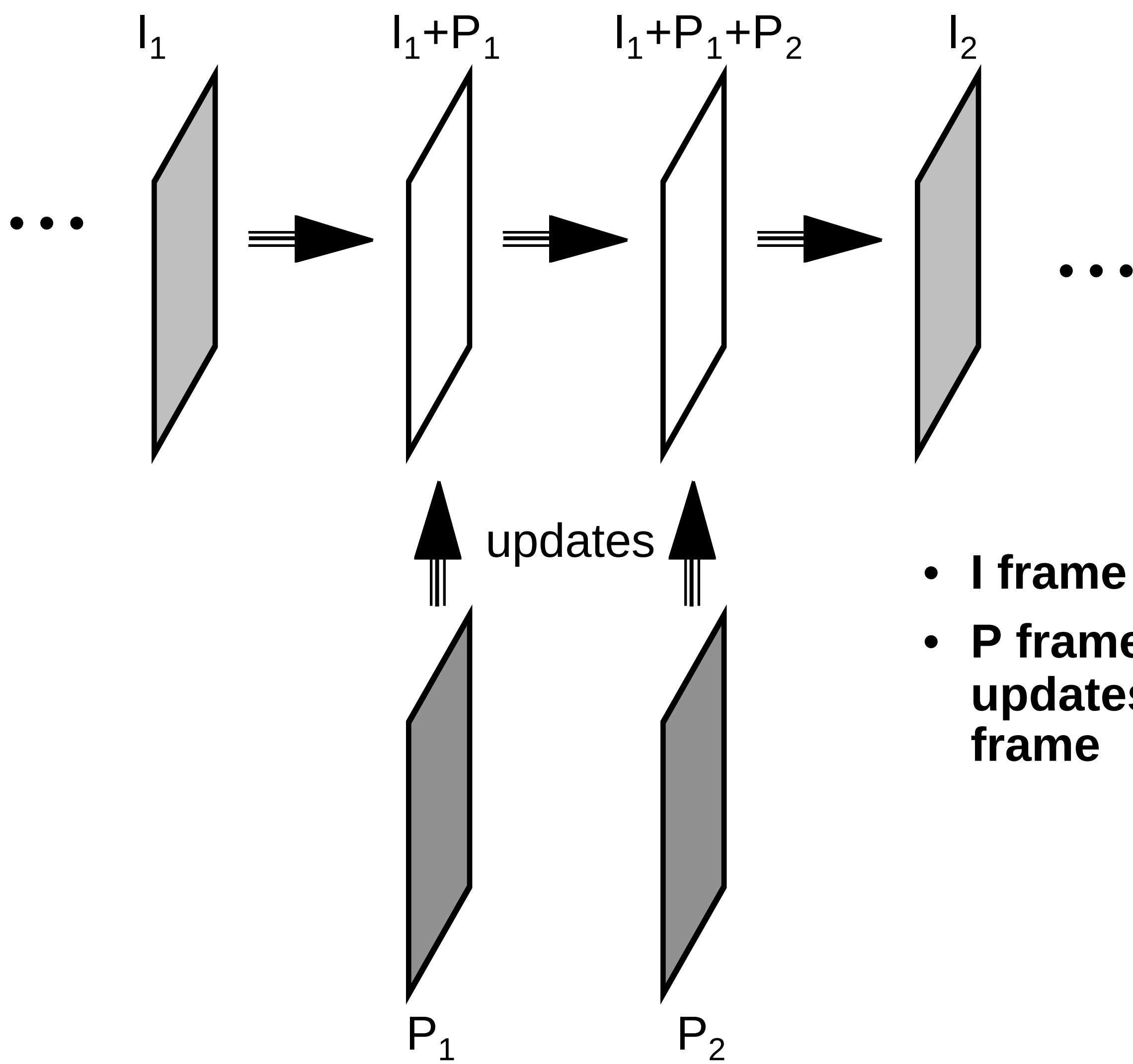


I_1 B_1 B_2 B_3 P_1 B_4 B_5 B_6 P_2 B_7 B_8 B_9 I_2

Frame Types

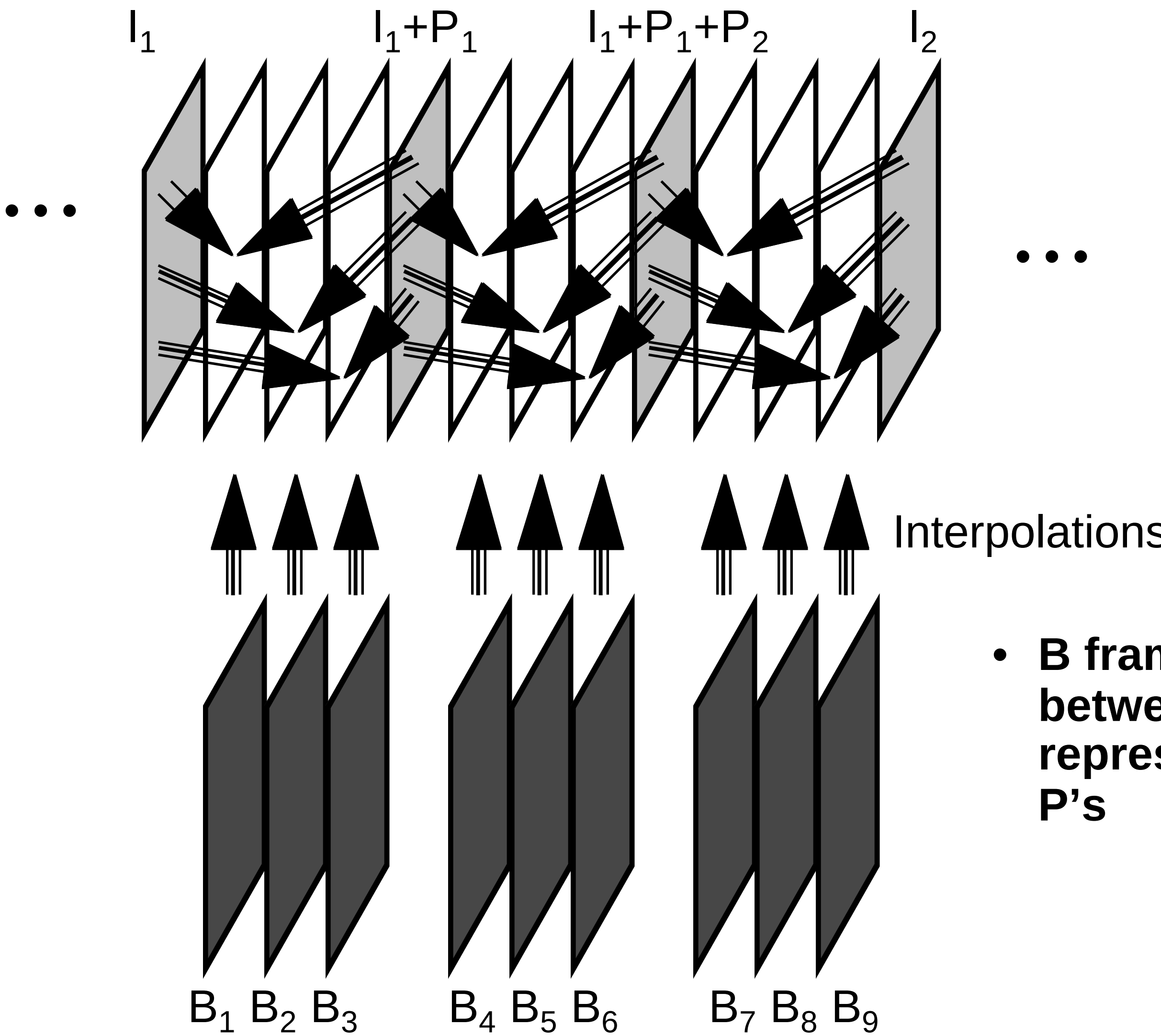
I	**Intra**	**Encode complete image, similar to JPEG**
P	**Forward Predicted**	**Motion relative to previous I and P's**
B	**Backward Predicted**	**Motion relative to previous & future I's & P's**

Frame Reconstruction



- **I frame complete image**
- **P frames provide series of updates to most recent I frame**

Frame Reconstruction (cont).



- **B frames interpolate between frames represented by I's & P's**

Updates / Interpolations

Describe how to construct 16 X 16 block in new frame

- Block from earlier frame
- Block from future frame (B frame only)
- Additive correction

Encoding

- All blocks coded using format similar to JPEG

Typical Numbers

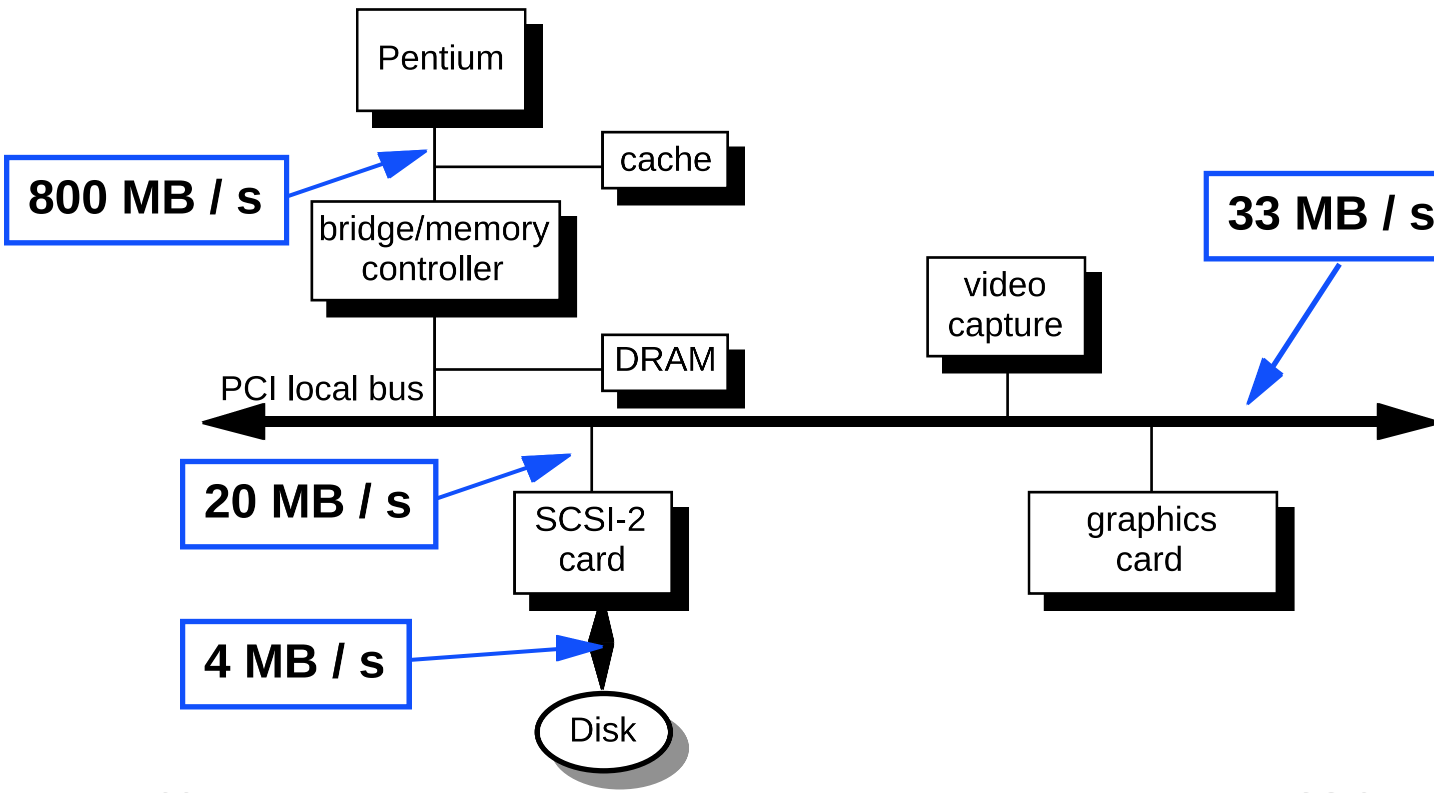
- 320 X 240 X 148 frames

• 10 I frames	18.9 KB average	6:1 compression
• 40 P frames	10.6 KB average	11:1 compression
• 98 B frames	0.8 KB average	141:1 compression
• 148 total	4.7 KB average	24:1 compression

Bandwidth Requirements

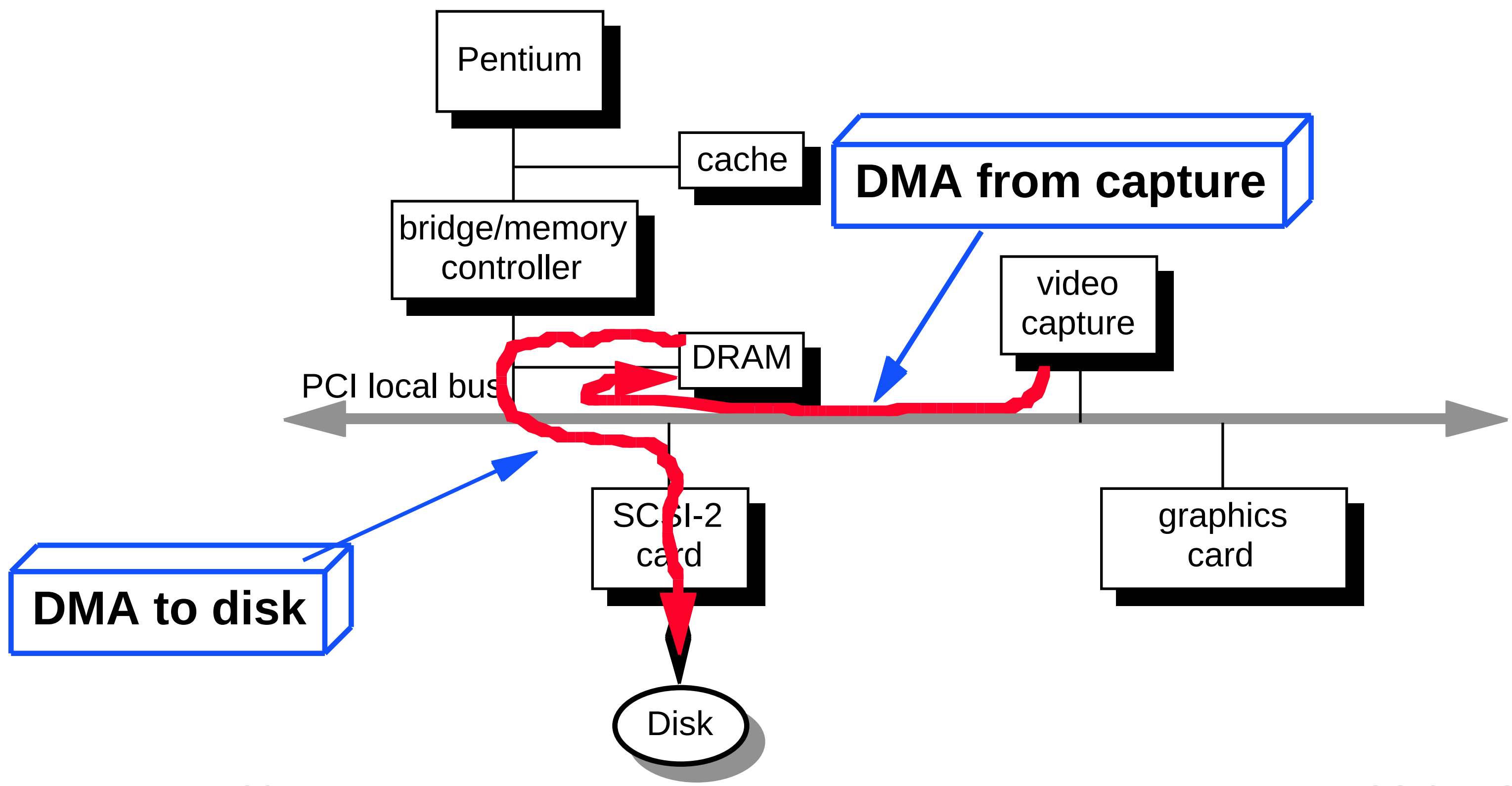
Consider MPEG-1 (352 X 240) vs. MPEG-2 (720 X 480)

- **Uncompressed** **3.6 MB / s** **14.8 MB / s**
- **Compressed** **0.14 MB / s** **0.43 MB / s**



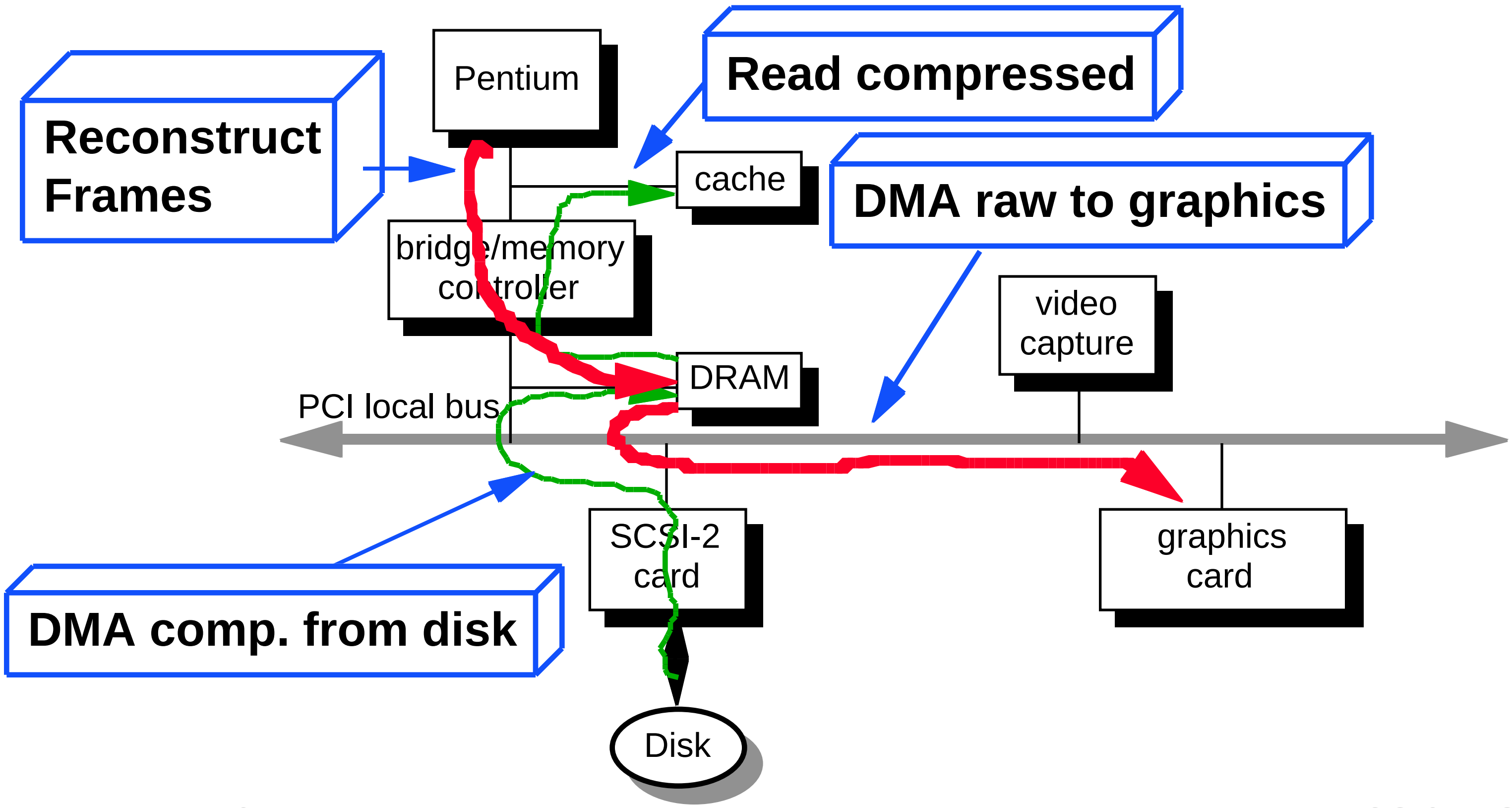
Capture Raw Video to Disk

	MPEG-1	MPEG-2	
PCI	7.2 MB / s	29.6 MB / s	(shaky)
SCSI-2	3.6 MB / s	14.8 MB / s	(OK)
Disk	3.6 MB / s	14.8 MB / s	(No Way!)



Decompress & Playback

	MPEG-1	MPEG-2	
PCI	7.5 MB / s	30.5 MB / s	(shaky)
SCSI-2	0.14 MB / s	0.43 MB / s	(OK)
Disk	0.14 MB / s	0.43 MB / s	(OK)



ISA Extensions to Support Multimedia

	MIPS V/ MDMX	Intel MMX	Sun VIS	HP MAX2	Alpha MVI
No. of Registers	32	8	32	31	31
Register Type	MM/FP†	MM/FP†	MM/FP†	Integer	Integer
Parallel Arithmetic	8 × 8 bits 4 × 16 bits	8 × 8 bits 4 × 16 bits	4 × 16 bits 2 × 32 bits	4 × 16 bits	Min/max only
Unsaturating?	No	Yes	Yes	Yes	n/a
Saturating?	Yes	Yes	No	Yes	n/a
Three Operands?	Yes	No (2)	Yes	Yes	Yes
Parallel Multiplies	4 or 8	4	4	None	None
Multiply/Add	8 × 8 → 24 16 × 16 → 48	16 × 16 → 32	8 × 16 → 16	Shift-and-add	None
Vector-to-Scalar?	Yes	No	No	No	No
Parallel Shifts?	Yes	Yes	No	Yes	No
Parallel Average?	No	No	No	Yes	No
Parallel Compare?	Yes	Yes	Yes	No	No
Pack/Unpack?	Yes	Yes	Yes	Yes	No
Interleave?	Yes	Yes	Yes	Yes	No
Permute?	No	No	No	Yes	No
Pixel Error?*	No	No	Yes	No	Yes
Block Load/Store?	No	No	Yes	No	No
Parallel FP?	Yes	No	No	No	No

Microprocessor Report 11/18/96

- **CPU manufacturers extending architectures to support multimedia**
- **Low precision (1 & 2 byte), saturating arithmetic**
- **Vector operations**

MIPS MMDX

Overload Use of FP Registers

- **64 bits total**
- **View as vector of small integers**
  - 8 single byte words
  - 4 two-byte words
- **Operations**
  - Addition, multiplication
    - » Different vector modes
    - » Saturating
  - Rearrange
    - » Shuffle, pack, unpack

Microprocessor Report 11/18/96

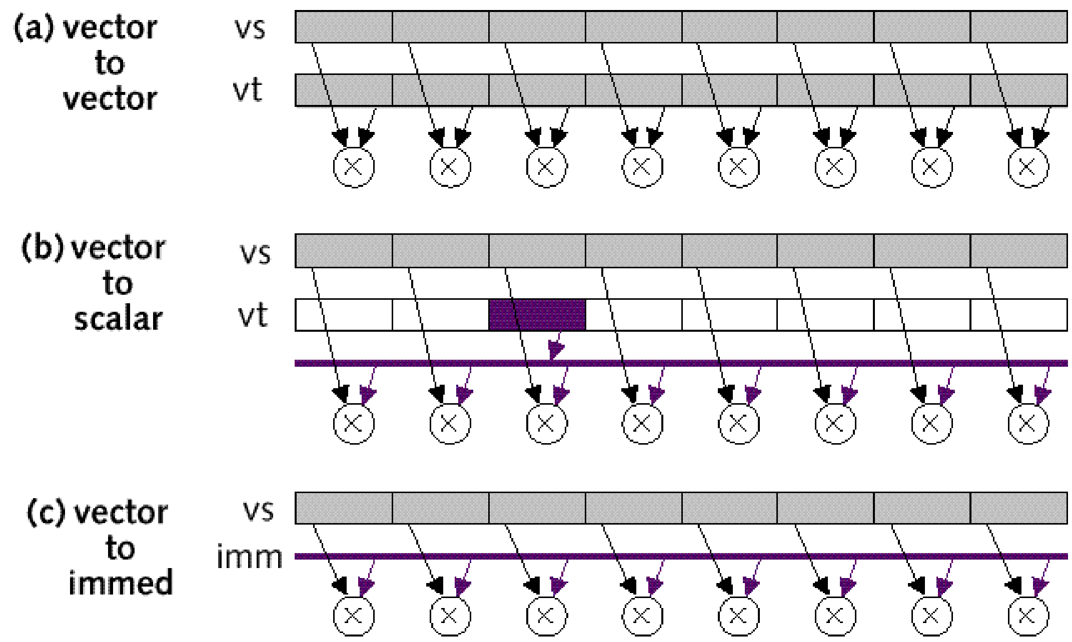


Figure 1. MDMX instructions operate in (a) vector-to-vector mode, (b) vector-to-scalar mode, and (c) vector-to-immediate mode.

Intel MMX

Similar to MIPS

- **Overload use of FP registers**
  - Only 8 available
- **View as vector of integers**
  - 1, 2, or 4 bytes each

Microprocessor Report 3/5/96

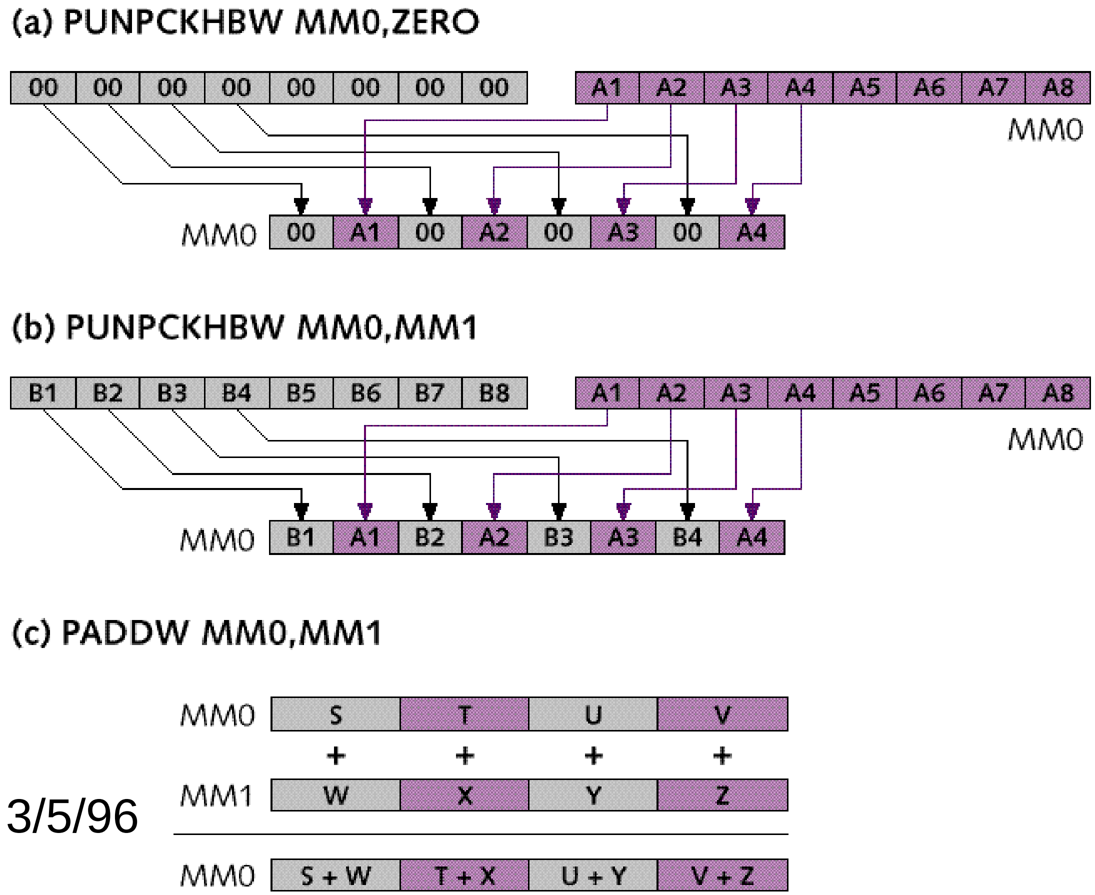


Figure 3. (a) Unpack operation converts packed bytes to words with zero extension. (b) PUNPCK can also interleave bytes from two MM registers. (c) Parallel add instruction calculates four 16-bit sums simultaneously.

Digital MVI

Standard Alpha

- **Can do most multimedia tasks in software**
  - Sledgehammers make good fly swatters
- **Cannot do MPEG-2 encoding in real time**
  - Motion estimation is very demanding
  - Must compare 16 X 16 blocks with blocks from other frames

Extensions

- **Packing & unpacking smaller (1, 2, 4 byte) integers**
- **Special instruction used in motion estimation**
  - Perr Ra, Rb, Rc
  - Ra, Rb vectors of single byte words
  - Rc = SUM(i = 0, 7) $| Ra_i - Rb_i |$