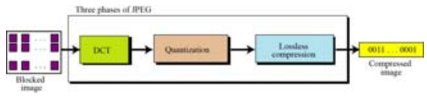
# Einführung in Visual Computing
## Unit 5: Image Encoding and Compression

http://www.caa.tuwien.ac.at/cvl/teaching/sommersemester/evc

- Content:
  - Introduction to Encoding
  - Image File Formats
  - Information vs. Data
  - Introduction into Compression
  - Lossless Compression
  - Lossy Compression
  - Video Compression



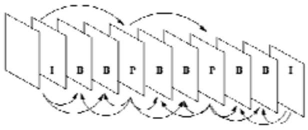
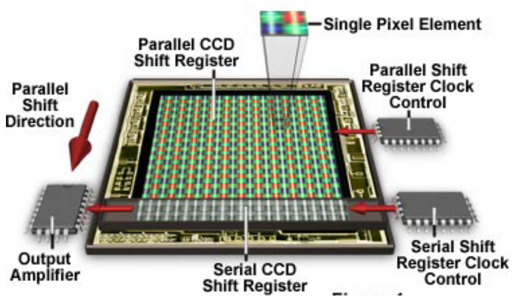



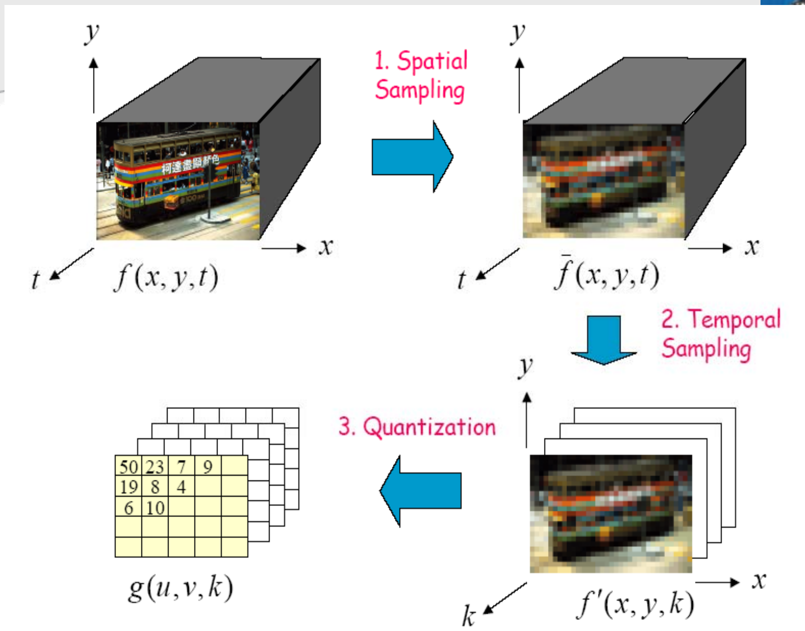

Figure 1: Prediction between MPEG 2 Frames



## Image Acquisition using CCDs

- Chip produces lines with analog values
- Fixed number of lines
- Lines are digitized
  - Space: Sampling
  - Intensity: Quantization
  - Time: Temporal Sampling
- Image Encoding
  - 2d matrix of digital values
  - File format?
  - Compression?







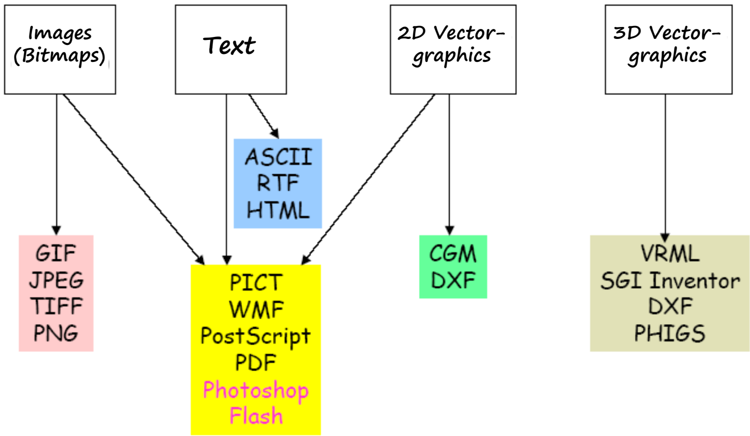

## Storage Requirements for Digital Images

- Image LxN pixels, $2^B$ gray levels, c color components

**Size = LxNxBxc**

  - Example: L=N=512, B=8, c=1 (i.e., monochrome)
    Size = 2,097,152 bits (or 256 kByte)
  - Example: LxN=1024x1280, B=8, c=3 (24 bit RGB image)
    Size = 31,457,280 bits (or 3.75 MByte)
- Much less with (lossy) compression!

# Image/Graphics Files






# What are the Categories?

One categorization:

- Raster Image Formats
- Vector Image Formats

Another categorization:

- Binary Image Formats
- ASCII Image Formats

Raster Image Formats



# Raster Image Formats

- Breaks the image into a series of color dots called “pixels”
- The number of bits at each pixel determines the maximum number of colors

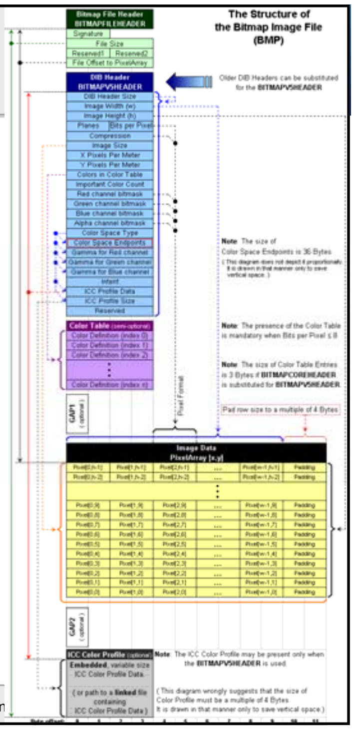
| | |
|---|---|
| 1 bits = 2 ($2^1$) colors | 2 bits = 4 ($2^2$) colors |
| 4 bits = 16 ($2^4$) colors | 8 bits = 256 ($2^8$) colors |
| 16 bits = 65,536 ($2^{16}$) colors | 24 bits = 16,777,216 ($2^{24}$) colors |

- Examples:
  - BMP/DIB: BitMaP or Device Independent Bitmap (DIB), Microsoft Windows and OS/2
  - PBM, PGM, PPM: Portable BitMap, GrayMap, PixMap, Unix, PC
  - TGA: Truevision Advanced Raster Graphics Adapter (TARGA), Avi

# Example: BMP Format

- The bitmap image file consists of:
  - fixed-size structures (headers)
  - variable-size structures (image)

| Structure Name | Optional | Size | Purpose | Comments |
|---|---|---|---|---|
| Bitmap File Header | No | 14 Bytes | To store general information about the Bitmap Image File | Not needed after the file is loaded in memory |
| DIB Header | No | Fixed-size (however 7 different versions exist) | To store detailed information about the bitmap image and define the pixel format | Immediately follows the Bitmap File Header |
| Extra bit masks | Yes | 3 or 4 DWORDs[2] (12 or 16 Bytes) | To define the pixel format | Present only in case the DIB Header is the BITMAPINFOHEADER |
| Color Table | Semi-optional | Variable-size | To define colors used by the bitmap image data (Pixel Array) | Mandatory for color depths <= 8 |
| Gap1 | Yes | Variable-size | Structure alignment | An artifact of the File Offset to PixelArray in the Bitmap File Header |
| Pixel Array | No | Variable-size | To define the actual values of the pixels | The pixel format is defined by the DIB Header or Extra bit masks. Each row in the Pixel Array is padded to a multiple of 4 bytes in size |
| Gap2 | Yes | Variable-size | Structure alignment | An artifact of the ICC Profile Data offset field in the DIB Header |
| ICC Color Profile | Yes | Variable-size | To define the color profile for color management | Can also contain a path to an external file containing the color profile. When loaded in memory as "non-packed DIB", it is located between the color table and gap1 |



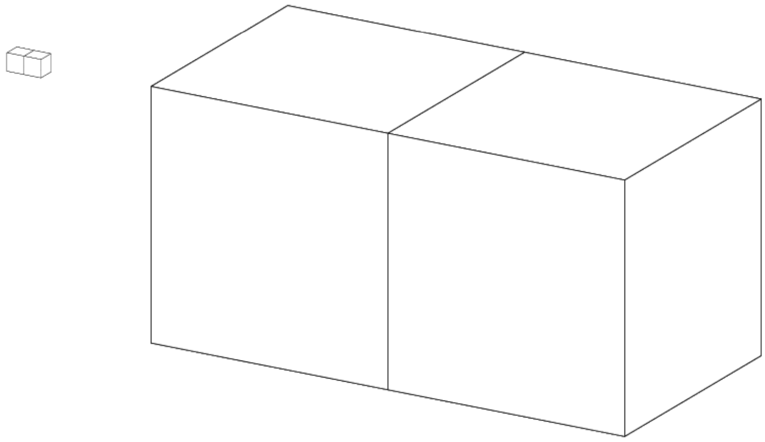



# Raster Image Formats

## … more Raster File Formats

- PICT (Apple Quicktime))
- RAS Sun Raster Format (Sun Microsystems)
- RGB (Silicon Graphics)
- RLE Utah Raster Toolkit (Run-Length Encoded)
- XBM/XPM X-Windows Bitmap/Pixmap (X-Consortium), ASCII!
- GIF, TIFF, JPEG …

## Instead …





# Vector Image Formats

## Vector Image Formats

- Break the image into a set of mathematical descriptions of shapes: curve, arc, rectangle, sphere etc.
- Resolution-independent: scalable without the problem of “pixelating”.
- Not all images are easily described in a mathematical form.
- How to describe a photograph?



## Vector Image Formats

- Break the image into a set of mathematical descriptions of shapes: curve, arc, rectangle, sphere etc.
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# CGM

- Goal: to make vector graphics portable across different operating systems
- Computer Graphics Metafile: 3 types of coding
  - Raster / vector format, ANSI standard for exchange of image data between different graphics software (device independent). Metafile contains data and information, which describes the organization and the semantics of the data. Due to the structuring of CGM is an ideal partner for HTML and SGML.
  - 1999: "Application Structuring,“ enables to use non-graphic information along with graphic content (interactive graphics, "Hot Spots,hyperlinks, etc.)
  - Different application profiles: define options, elements and parameters necessary to enable specific functions and the interchangeability of the systems



# WMF - Windows MetaFile

- Graphics file format on Microsoft Windows systems, originally designed in the 1990s. Windows Metafiles are intended to be portable between applications and may contain both vector graphics and bitmap components.
- WMF file stores a list of function calls that have to be issued to the Windows Graphics Device Interface (GDI) layer to display an image on screen.
- EMF (Enhanced Metafile) 32bit extension to 16bit- WMF
- EMF+ with Windows XP

## Comparison

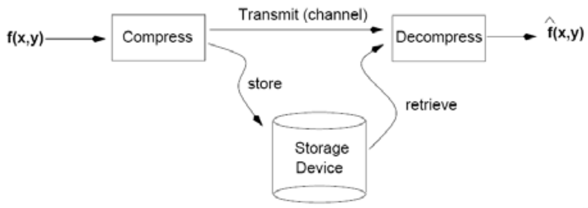
- Raster
  - Resolution-dependent
  - Suitable for photographs
  - Smooth tones and subtle details
  - Larger size
- Vector
  - Resolution-independent
  - Suitable for line drawings, CAD, logos
  - Smooth curves
  - Smaller size



## Image Compression

## Goal of Image Compression

- Digital images require huge amounts of space for storage and large bandwidths for transmission.
  - A 640 x 480 color image requires close to 1MB of space.
- The goal of image compression is to reduce the amount of data required to represent a digital image.
  - Reduce storage requirements and increase transmission rates.






## Data ≠ Information

- Data and information <u>are not</u> synonymous terms!
- **Data** is the means by which **information** is conveyed.
- Data compression aims to reduce the amount of data required to represent a given quantity of information while preserving as much information as possible.

## Data vs Information (cont'd)

- The same amount of information can be represented by various amount of data, e.g.:

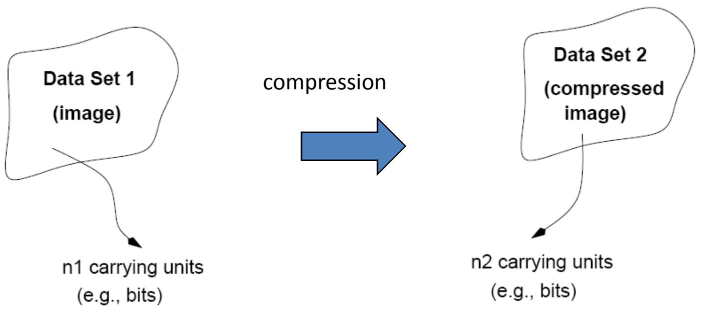
Ex1: *Your wife, Helen, will meet you at Logan Airport in Boston at 5 minutes past 6:00 pm tomorrow night*

Ex2: *Your wife will meet you at Logan Airport at 5 minutes past 6:00 pm tomorrow night*

Ex3: *Helen will meet you at Logan at 6:00 pm tomorrow night*



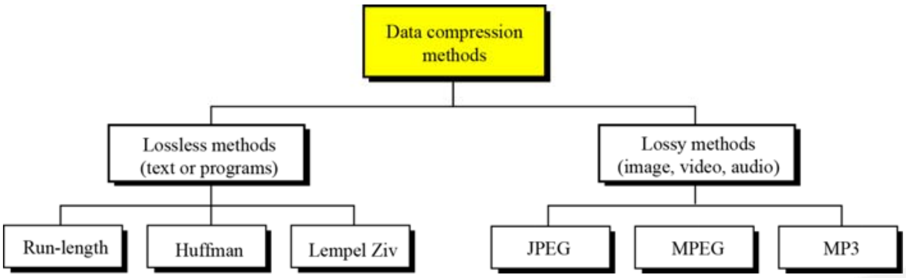
## Data Redundancy




Compression ratio: $C_R = \frac{n_1}{n_2}$

# Data Compression

- Data compression implies sending or storing a smaller number of bits.
  - lossless and
  - lossy methods.
  - Trade-off: image quality **vs** compression ratio






# Lossless Image Compression

## Run Length Encoding (RLE)

- Spatial and temporal neighboring pixels have similar intensity (colors)

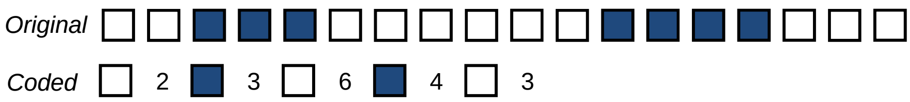
*spatial*

*temporal*



## Run Length Encoding (RLE)

- Simplest method of compression
- Can be used to compress data made of any combination of symbols, does not need to know the frequency of occurrence of symbols
- Replace consecutive repeating occurrences of a symbol by one occurrence of the symbol followed by the number of occurrences




- Lossless compression!

# Huffman Coding

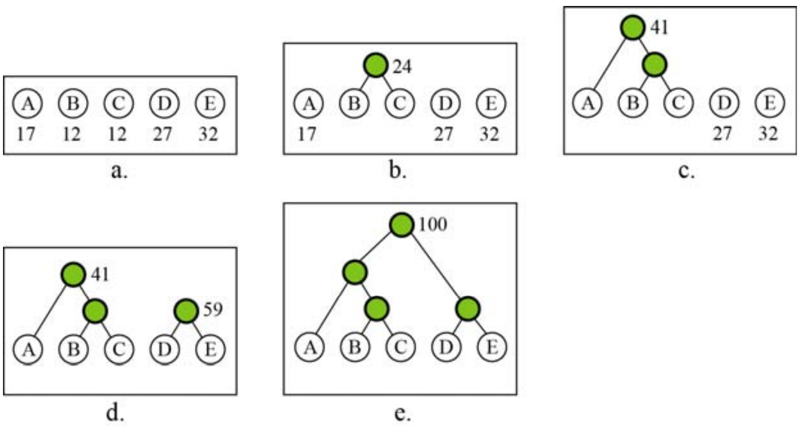
- Assigns shorter codes to symbols that occur more frequently and longer codes to those that occur less frequently.
- Example text file with five characters (A, B, C, D, E):
  - Assign each character a weight based on its frequency of use

Frequency of characters

| Character | A | B | C | D | E |
|---|---|---|---|---|---|
| Frequency | 17 | 12 | 12 | 27 | 32 |

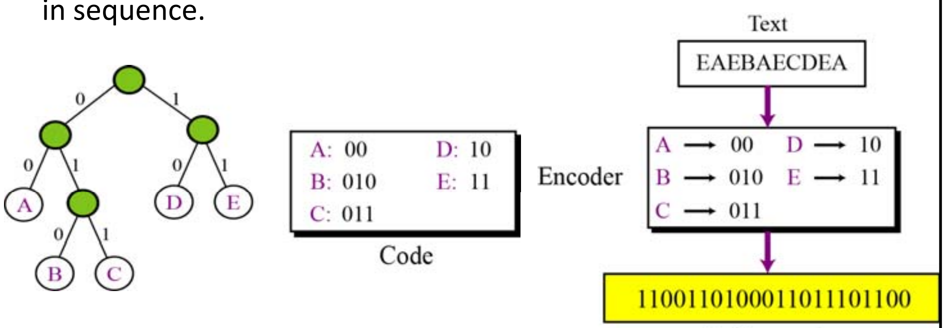


# Huffman Encoding



# Huffman Encoding

- Character code found by starting at the root and following the branches that lead to that character.
- The code itself is the bit value of each branch on the path, taken in sequence.



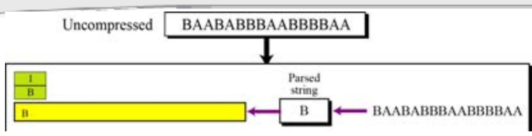

- Decoding: reverse process



# Lempel Ziv (LZ) Dictionary-based Encoding

- Dictionary is a table of strings
  - Sender and receiver have a copy of dictionary
  - Previously-encountered strings are substituted by their index in dictionary
- Compression - two concurrent events:
  - Building an indexed dictionary
  - Compressing a string of symbols.
- Algorithm extracts smallest substring not in the dictionary from remaining uncompressed string.
- Stores a copy of this substring in dictionary as a new entry and assigns it an index value.
- Compression occurs when substring (except for the last character) is replaced with the index found in the dictionary.
- Process inserts the index and the last character of the substring into the compressed string.

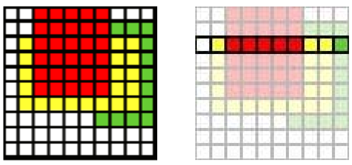
# Example of Lempel Ziv Encoding






# Lossless Image Formats

- GIF-Format (Graphics Interchange Format)
  - LZW-Compression (Lempel, Ziv, Welch): works line-wise



  - 1 st line, 2nd line
  - 3rd line is compressed as:
    - 1 white, 1 yellow, 5 red, 2 yellow, 1 green
  - Row 4 to 6: „as row 3“
- Indexed (1-8 bit Color Lookup Table)

# CompuServ GIF (gif)

- First standardized in 1987 by CompuServ (called GIF87a)
- Updated in 1989 to include transparency, interlacing, and animation (called GIF89a)
- Use the LZW (Lempel-Ziv Welch) algorithm for compression (not free, licenses necessary)
- A maximum of 256 colors freely selectable out of 24 bit ($2^{24}$ = 16.777.216)
- Does not work for photographs
- Suitable for small images such as icons
- Simple animations



# Portable Network Graphics (png)

- Developed because of licensed LZW with gif
- Replacing GIF and TIFF (not JPEG!)
- 3 Types
  - True Color (3 x 16 bit/pixel)
  - Grayscale (1 x 8 bit/pixel)
  - Palette (256 colors)
- Compression similar to PKZIP (Phil Katz)

## Tagged Image File Format (tiff)

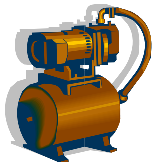
- originally created as an attempt to get desktop scanner vendors of 1985 to agree on a common scanned image file format, rather than have each company promote its own proprietary format
- Aldus/Microsoft/Adobe
- Flexible and extendible because of „tags“
- Indexed or True-color
- Compressed/uncompressed (Raw)
- No standardization, more than 50 different formats
- JPEG compression



## Lossy Image Compression

## Lossy Compression

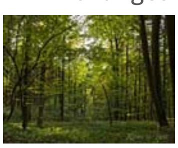
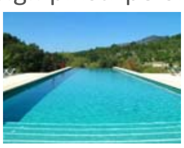
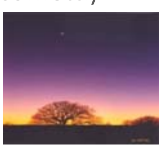
- Run-length coding works well for simple images (graphics) and computer data
- However, a large, detailed picture usually is not reduced enough
- In order to reduce information further lossy compression is needed
  - Information is permanently removed
  - The trick is to remove details that are not perceived by a human observer
  - Many of these psycho-visual coding systems take advantage of a number of aspects of the human visual system





## Human Visual System

- The eye is more sensitive to brightness changes than to color changes
- The eye is not able to perceive brightness above or below certain threshold values
- The eye does not perceive little brightness or color changes. The strength of this phenomenon is dependent on the color
  - Certain luminance / color range visually more important than others (eg greens of leaves and plants in the forest can be distinguished better than various shades of blue at the bottom of a swimming pool)
  - Gentle brightness or color transitions (eg sunset, running into the blue sky) are important for the eye and are perceived as more abrupt changes (e.g.: pinstripe or confetti)

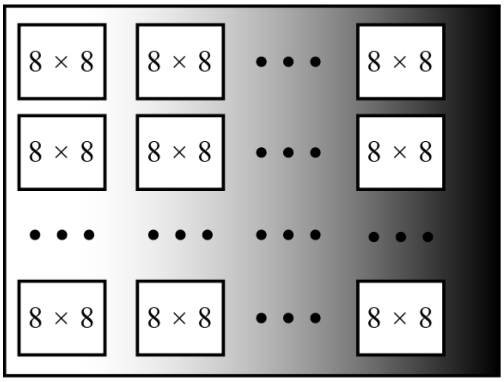
## Compression of Still Images

- Characteristics of human vision have been transferred to lossy image compression techniques
- Such a development is the JPEG format
  - Stands for "Joint Photographic Experts Group"
  - JPEG is the worldwide standard
  - JPEG compresses brightness and color information separately
  - Color information is more compressed (lower sensitivity)
- Color space for JPEG compression
  - RGB values are a combination of brightness and color
  - If the RGB values are separated into a luminance and a color component, the color component is more compressed



## JPEG Compression

- Image is divided into blocks of 8 × 8 pixel blocks to decrease the number of calculations because the number of mathematical operations for each image is the square of the number of units.



# JPEG Compression

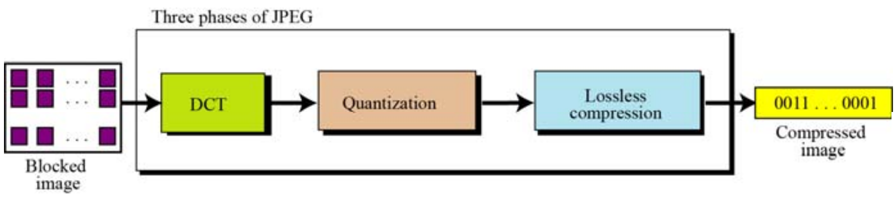
- Colorspace conversion and Downsampling:
  - Separation of the color components of the luminance information
  - Insensitivity of human eye to rapid color changes allows coarser sampling of the color components
    -> No loss of subjective quality
    -> Significant data reduction

- DCT ant Quantization in spectral component
  - DCT for 8x8
  - Quantization of the 64 spectral coefficients by a quantization table (table determines quality of compressed image)

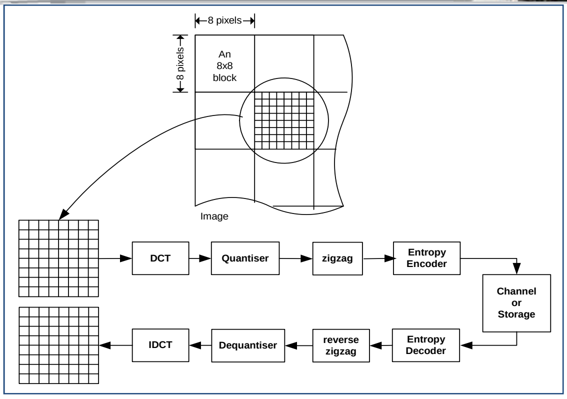


# JPEG Compression

- Idea: change image into a linear (vector) set of numbers that reveals redundancies.
- Redundancies can be removed using one of the lossless compression methods



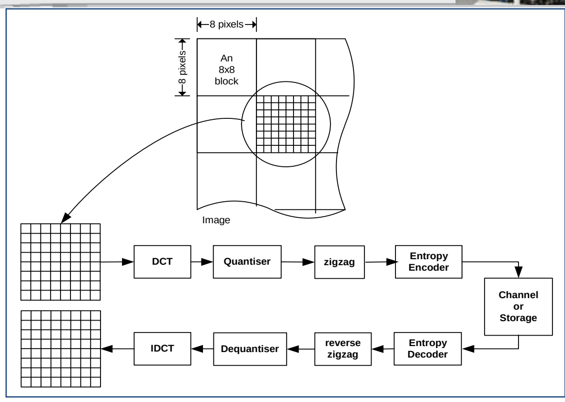
# JPEG Compression




- To perform the JPEG coding, an image (in color or grey scales) is first subdivided into blocks of 8x8 pixels.
- The Discrete Cosine Transform (DCT) is then performed on each block.
- This generates 64 coefficients which are then quantized to reduce their magnitude.



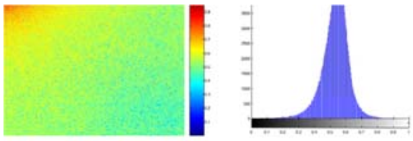
# JPEG Compression



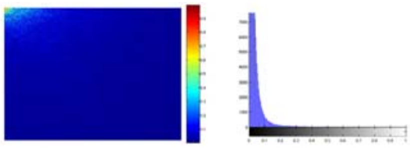

- The coefficients are then reordered into a one-dimensional array in a zigzag manner before further entropy encoding.
- The compression is achieved in two stages; the first is during quantization and the second during the entropy coding process.
- JPEG decoding is the reverse process of coding.

## Discrete Cosine Transform

- Similar to Discrete Fourier Transform (DFT) but much better for energy compactation
  - Example: we see amplitude spectra of image under DFT and DCT
  - note the much more concentrated histogram obtained with DCT
- why is energy compaction important?
  - the main reason is image compression



DFT

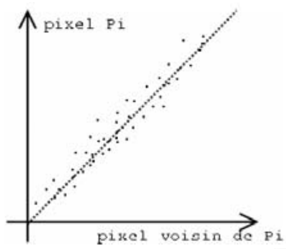


DCT



## DCT

- The transform throws away correlations
  - If you make a plot of the value of a pixel as a function of one of its neighbors
  - You will see that the pixels are highly correlated (i.e. most of the time they are very similar)
  - This is just a consequence of the fact that surfaces are smooth



# DCT

- DCT-based codecs use a two-dimensional version of the transform.
- The 2-D DCT of an 8 x 8 block:

$$F(u,v)=\sum_{x=0}^{7}\sum_{y=0}^{7}\alpha(u)\alpha(v)f(x,y)\cos\left[\frac{\pi}{8}\left(x+\frac{1}{2}\right)u\right]\cos\left[\frac{\pi}{8}\left(y+\frac{1}{2}\right)v\right]$$

$u$ is the horizontal spatial frequency, for the integers $0 \le u < 8$

$v$ is the vertical spatial frequency, for the integers $0 \le v < 8$

$\alpha(u)=\begin{cases}\sqrt{\frac{1}{8}}, & \text{if } u=0\\ \sqrt{\frac{2}{8}}, & \text{otherwise}\end{cases}$ is a normalizing scale factor to make the transformation orthonormal

$f(x,y)$ is the pixel value at coordinates $(x,y)$

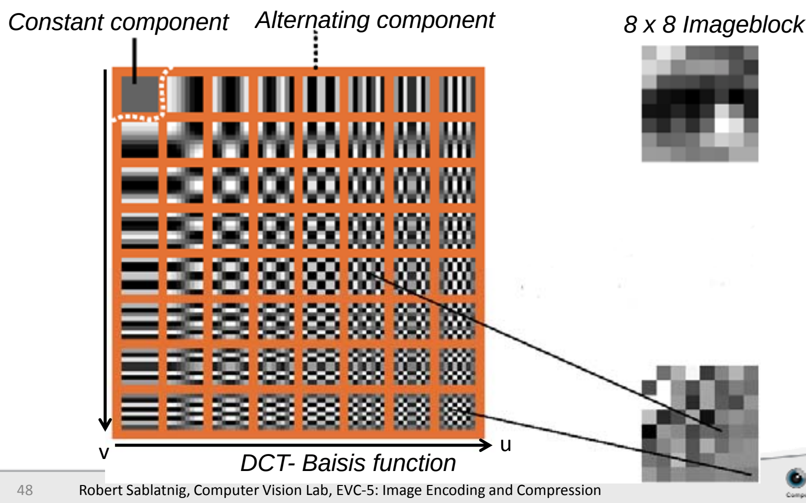
$F(u,v)$ is the DCT coefficient at coordinates $(u,v)$

◆ **Note: The DCT decomposes a signal into a series of harmonic cosine functions.**



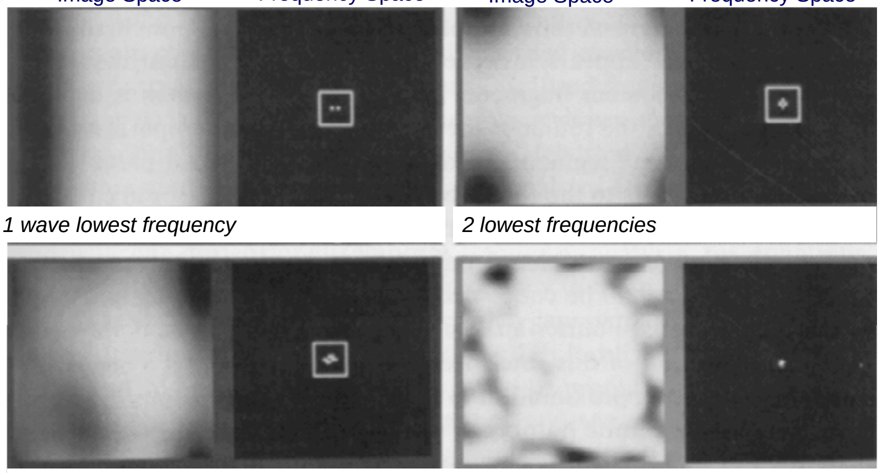
# DCT Basis Functions

- DCT values indicate the weighting of frequency images
- The brighter the pixel, the greater the value of DCT



# Decomposing into Frequencies

Image Space | Frequency Space | Image Space | Frequency Space



*1 wave lowest frequency* | *2 lowest frequencies*

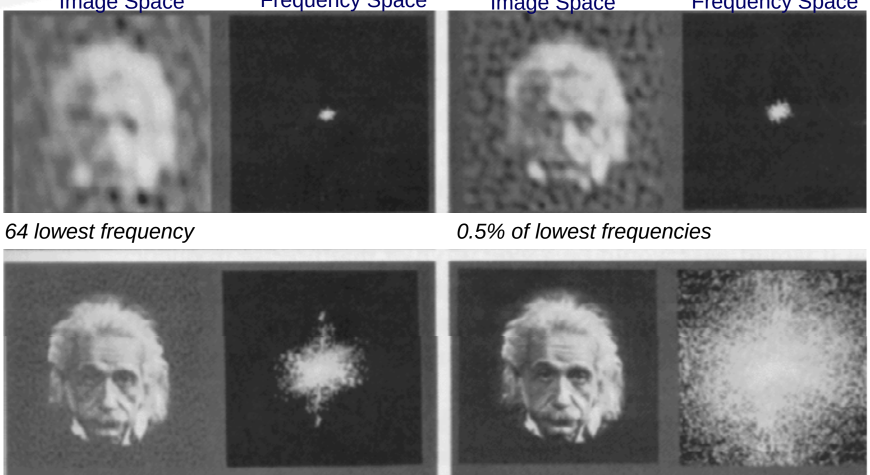
*4 lowest frequencies* | *16 lowest frequencies*

*(Example computed with DFT, which is similar to DCT)*



# Decomposing into Frequencies

Image Space | Frequency Space | Image Space | Frequency Space



*64 lowest frequency* | *0.5% of lowest frequencies*

*20% of lowest frequencies* | *All frequencies*

*(Example computed with DFT, which is similar to DCT)*

# DCT

- DCT sorts values from the lowest to the highest frequency
- In image blocks it is likely that the energy is concentrated in low frequencies
  - Regions with smooth colors or little details (= low spatial frequencies) have high values
  - Regions with different colors and detail (= high spatial frequencies), most values are almost zero.

*8x8 Block (Luminance)*

| | | | | | | |
|---|---|---|---|---|---|---|
| 134 | 142 | 145 | 131 | 114 | 122 | 131 |
| 129 | 143 | 134 | 130 | 135 | 144 | 134 |
| 123 | 117 | 118 | 111 | 97 | 109 | 130 |
| 129 | 116 | 112 | 116 | 120 | 126 | 130 |
| 118 | 127 | 141 | 138 | 138 | 148 | 141 |
| 125 | 129 | 119 | 127 | 143 | 149 | 145 |
| 131 | 126 | 128 | 142 | 141 | 135 | 126 |
| 131 | 140 | 146 | 154 | 133 | 118 | 124 |

*Pixelvalues*

Low frequencies

| | | | | | | |
|---|---|---|---|---|---|---|
| 1037 | -1 | -6 | 1 | -12 | 8 | -4 |
| -16 | 1 | 28 | -6 | -14 | 0 | 4 |
| 19 | 32 | -7 | -19 | 2 | -1 | -4 |
| 29 | -9 | -14 | 13 | -10 | -6 | 1 |
| 4 | 14 | -6 | -13 | -2 | 7 | 1 |
| -26 | 2 | 16 | 2 | 11 | 6 | 1 |
| -10 | -11 | 27 | -18 | 4 | 1 | 0 |
| -2 | 1 | 1 | -19 | -1 | 6 | 6 |

High frequencies

*DCT- Values*



# DCT Examples


Block

uniform

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |

P (x, y)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 160 | 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 |
| 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 | 0 |

***T (u,v)***


Block

step

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |
| 20 | 20 | 20 | 20 | 50 | 50 | 50 | 50 |

P (x, y)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 200 | −100 | 0 | 39 | 0 | −25 | −1 | 22 |
| 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 | 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 |

***T (u,v)***

# DCT Examples

8 × 8

Block

gradient grayscale

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |

P $(x, y)$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 400 | −146 | 0 | −31 | −1 | 3 | −1 | −8 |
| 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 | 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 |

$T(u,v)$



# Quantization

- Compression effect: DCT values are approximated (quantized) to make them smaller and to repeat themselves
  - Each DCT value is divided by a quantization factor and then rounded
  - The larger the quantization factor, the smaller the values to be stored

| | | | | | | |
|---|---|---|---|---|---|---|
| 134 | 142 | 145 | 131 | 114 | 122 | 131 |
| 129 | 143 | 134 | 130 | 135 | 144 | 134 |
| 123 | 117 | 118 | 111 | 97 | 109 | 130 |
| 129 | 116 | 112 | 116 | 120 | 126 | 130 |
| 118 | 127 | 141 | 138 | 138 | 148 | 141 |
| 125 | 129 | 119 | 127 | 143 | 149 | 145 |
| 131 | 126 | 128 | 142 | 141 | 135 | 126 |
| 131 | 140 | 146 | 154 | 133 | 118 | 124 |

*Pixelvalues*

| | | | | | | |
|---|---|---|---|---|---|---|
| 1037 | -1 | -6 | 1 | -12 | 8 | -4 |
| -16 | 1 | 28 | -6 | -14 | 0 | 4 |
| 19 | 32 | -7 | -19 | 2 | -1 | -4 |
| 29 | -9 | -14 | 13 | -10 | -6 | 1 |
| 4 | 14 | -6 | -13 | -2 | 7 | 1 |
| -26 | 2 | 16 | 2 | 11 | 6 | 1 |
| -10 | -11 | 27 | -18 | 4 | 1 | 0 |
| -2 | 1 | 1 | -19 | -1 | 6 | 6 |

*DCT- Values*

| | | | | | | |
|---|---|---|---|---|---|---|
| 130 | 0 | 0 | 0 | -1 | 0 | 0 |
| -2 | 0 | 3 | 0 | -1 | 0 | 0 |
| 2 | 3 | 0 | -1 | 0 | 0 | 0 |
| 3 | -1 | -1 | 1 | 0 | 0 | 0 |
| 0 | 1 | 0 | -1 | 0 | 0 | 0 |
| -2 | 0 | 2 | 0 | 0 | 0 | 0 |
| -1 | -1 | 2 | -1 | 0 | 0 | 0 |
| 0 | 0 | 0 | -1 | 0 | 0 | 0 |

*Quantized DCT- Values*

## Quantization Matrix

- Quantization factor for each DCT value is defined using a quantization matrix
  - Disturbances in low frequency parts of the image are perceived strongly
  - Disturbances in high frequency parts of the image are less noticeable
  - Quantization matrices in JPEG standard ensures that the DCT values for low frequencies are stored more accurately than for high frequencies
  - Quantization table can be freely selected in the compression

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | 16 | 19 | 22 | 26 | 27 | 29 | 34 |
| 16 | 16 | 22 | 24 | 27 | 29 | 34 | 37 |
| 19 | 22 | 26 | 27 | 29 | 34 | 34 | 38 |
| 22 | 22 | 26 | 27 | 29 | 34 | 37 | 40 |
| 22 | 26 | 27 | 29 | 32 | 35 | 40 | 48 |
| 26 | 27 | 29 | 32 | 35 | 40 | 48 | 58 |
| 26 | 27 | 29 | 34 | 38 | 46 | 56 | 69 |
| 27 | 29 | 35 | 38 | 46 | 56 | 69 | 83 |

*Quantization Matrix*

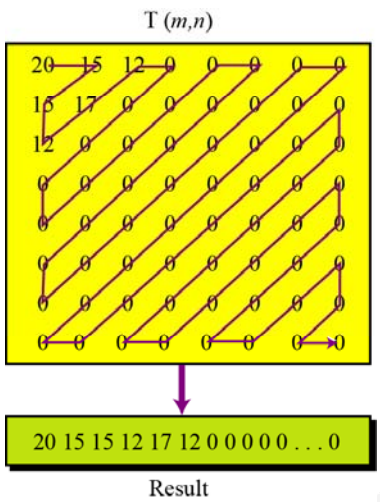
$$\begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120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

*Quantization Matrix*



## Compression

- After quantization values are read from the table, and redundant 0s are removed.
- To cluster 0s together process reads the table diagonally in a zigzag fashion because if image does not have fine changes bottom right corner of table is all 0s.
- JPEG uses run-length encoding at the compression phase to compress the bit pattern resulting from the zigzag linearization.



# Quantization

## Coding

| | | | | | | |
|---|---|---|---|---|---|---|
| 134 | 142 | 145 | 131 | 114 | 122 | 131 |
| 129 | 143 | 134 | 130 | 135 | 144 | 134 |
| 123 | 117 | 118 | 111 | 97 | 109 | 130 |
| 129 | 116 | 112 | 116 | 120 | 126 | 130 |
| 118 | 127 | 141 | 138 | 138 | 148 | 141 |
| 125 | 129 | 119 | 127 | 143 | 149 | 145 |
| 131 | 126 | 128 | 142 | 141 | 135 | 126 |
| 131 | 140 | 146 | 154 | 133 | 118 | 124 |

*Pixelvalues*

| | | | | | | |
|---|---|---|---|---|---|---|
| 1037 | -1 | -6 | 1 | -12 | 8 | -4 |
| -16 | 1 | 28 | -6 | -14 | 0 | 4 |
| 19 | 32 | -7 | -19 | 2 | -1 | -4 |
| 29 | -9 | -14 | 13 | -10 | -6 | 1 |
| 4 | 14 | -6 | -13 | -2 | 7 | 1 |
| -26 | 2 | 16 | 2 | 11 | 6 | 1 |
| -10 | -11 | 27 | -18 | 4 | 1 | 0 |
| -2 | 1 | 1 | -19 | -1 | 6 | 6 |

*DCT- Values*

| | | | | | | |
|---|---|---|---|---|---|---|
| 130 | 0 | 0 | 0 | -1 | 0 | 0 |
| -2 | 0 | 3 | 0 | -1 | 0 | 0 |
| 2 | 3 | 0 | -1 | 0 | 0 | 0 |
| 3 | -1 | -1 | 1 | 0 | 0 | 0 |
| 0 | 1 | 0 | -1 | 0 | 0 | 0 |
| -2 | 0 | 2 | 0 | 0 | 0 | 0 |
| -1 | -1 | 2 | -1 | 0 | 0 | 0 |
| 0 | 0 | 0 | -1 | 0 | 0 | 0 |

*Quantized DCT- Values*

## Decoding

| | | | | | | |
|---|---|---|---|---|---|---|
| 1040 | 0 | 0 | 0 | -9 | 0 | 0 |
| -12 | 0 | 24 | 0 | -10 | 0 | 0 |
| 14 | 24 | 0 | -10 | 0 | 0 | 0 |
| 24 | -8 | -9 | 10 | 0 | 0 | 0 |
| 0 | 9 | 0 | -10 | 0 | 0 | 0 |
| -19 | 0 | 10 | 0 | 0 | 0 | 0 |
| -9 | -10 | 21 | -12 | 0 | 0 | 0 |
| 0 | 0 | 0 | -14 | 0 | 0 | 0 |

*reconstructed DCT- Values*

| | | | | | | |
|---|---|---|---|---|---|---|
| 136 | 141 | 138 | 125 | 119 | 125 | 132 |
| 136 | 137 | 133 | 130 | 134 | 139 | 133 |
| 121 | 125 | 122 | 112 | 107 | 117 | 130 |
| 125 | 123 | 119 | 117 | 121 | 128 | 127 |
| 123 | 129 | 135 | 139 | 140 | 139 | 136 |
| 129 | 125 | 124 | 130 | 139 | 144 | 141 |
| 129 | 130 | 134 | 139 | 140 | 135 | 127 |
| 132 | 138 | 144 | 141 | 131 | 122 | 122 |

*Reconstructed Pixels (IDCT)*

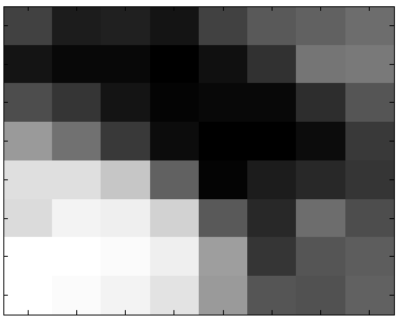
| | | | | | | |
|---|---|---|---|---|---|---|
| -2 | 1 | 7 | 6 | -5 | -3 | -1 |
| -7 | 6 | 1 | 0 | 1 | 5 | 1 |
| 2 | -8 | -4 | -1 | -10 | -8 | 0 |
| 4 | -7 | -7 | -1 | -1 | -2 | 3 |
| -5 | -2 | 6 | -1 | -2 | 9 | 5 |
| -4 | 4 | -5 | -3 | 4 | 5 | 4 |
| 2 | -4 | -6 | 3 | 1 | 0 | -1 |
| 1 | 2 | 2 | 13 | 2 | -4 | 1 |

*Difference*

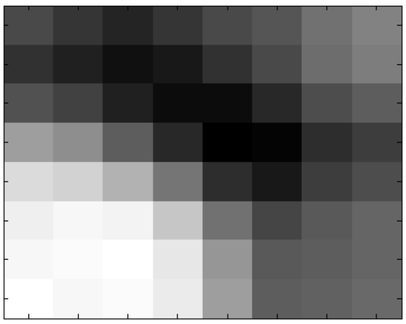


# Can You Tell the Difference?

Original



Compressed



## Image Compression

Original

Compressed



## JPEG Properties

- Weakness:
  - Behavior in sharp transitions (eg fonts)
  - Emergence of the 8x8 blocks at high compression rates.
- JPEG compression can reduce an image to a fifth of its original size (without visual impairment)
- The greater the compression (quantization), the more artefacts occur (block formation)
- JPEG is made for natural images and not for artificial images (computer graphics)!

# Video Compression

61

## Evolution of Video Media

- Film
  - Invented in late 18th century, still widely used today
- VHS
  - Released in 1976, rapidly disappearing

62 Robert Sablatnig, Computer Vision Lab, EVC-5: Image Encoding and Compression

# Evolution of Video Media

- DVD
  - Released in 1996, dominant for over a decade
- Hard Disk
  - Around for many years, only recently widely used for storing video (helped by explosion of Internet)



# Videocompression

- Single Image
  - Size 720 x 576 px
  - Pixelresolution: 1 Byte/RGB Value

    → 720 x 576 x 3 (Byte) ~ 1.215 KB
- Image sequence
  - 25 fps

    → 720 x 576 x 25 x 3 (Byte) ~ 30.375 KB/s

## TMI! (Too Much Information)

- Unlike image encoding, video encoding is rarely done in lossless form
- No storage medium has enough capacity to store a practical sized lossless video file
  - Lossless DVD video - 221 Mbps
  - Compressed DVD video - 4 Mbps
  - 50:1 compression ratio!

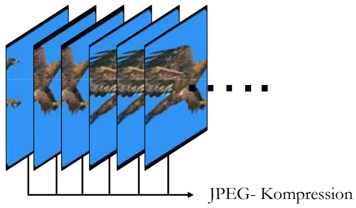


## Definitions

- Bitrate
  - Information stored/transmitted per unit time
  - Usually measured in Mbps (Megabits per second)
  - Ranges from < 1 Mbps to > 40 Mbps
- Resolution
  - Number of pixels per frame
  - Ranges from 160x120 to 1920x1080
- FPS (frames per second)
  - Usually 24(cinema), 25 (PALi, HDTVi), 30 (NTSCi), or 50,60 (DVD, HDTVp)
  - Don’t need more because of limitations of the human eye (16)

# M- JPEG

- Videosequenzes
- Single image compression using JPEG




| Benefits | Drawbacks |
|---|---|
| Constant Image Quality | Fluctuating bandwidth / frame rate |
| Fast computation | High memory requirements |
| Robust with respect to packet loss | No Audio |



# Delta- JPEG

- Differential image compression method
- Compression algorithm JPEG
- First image compressed
- Subsequent images only differences between images
- Additional image storage for transmitter and receiver
- Compression ratio changes depending on image changes

## MPEG (Moving Pictures Expert Group)

- Committee of experts that develops video encoding standards
- Until recently, was the only game in town (still the most popular, by far)
- Suitable for wide range of videos
  - Low resolution to high resolution
  - Slow movement to fast action
- Can be implemented either in software or hardware

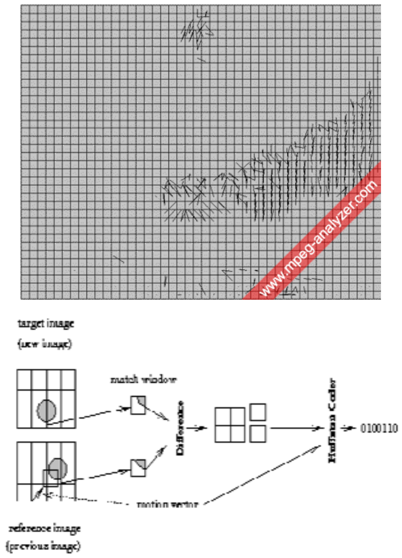


## MPEG Video Spatial Domain Processing

- Spatial domain handled very similarly to JPEG
  - Convert RGB values to YUV colorspace
  - Split frame into 8x8 blocks
  - 2-D DCT on each block
  - Quantization of DCT coefficients
  - Run length and entropy coding

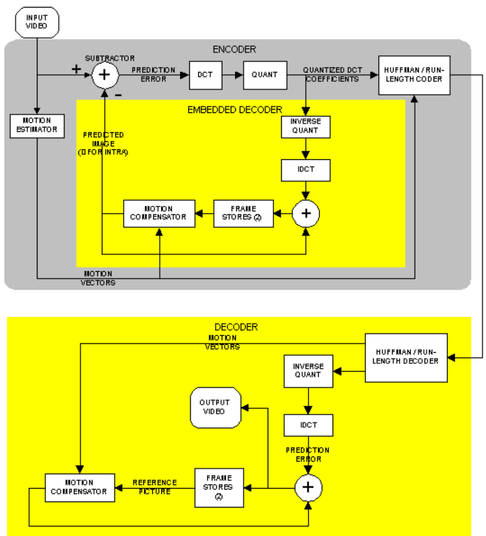
# MPEG Video Time Domain Processing

- General idea – Use motion vectors to specify how a 16x16 macroblock translates between reference frames and current frame, then code difference between reference and actual block






# MPEG Block Diagram



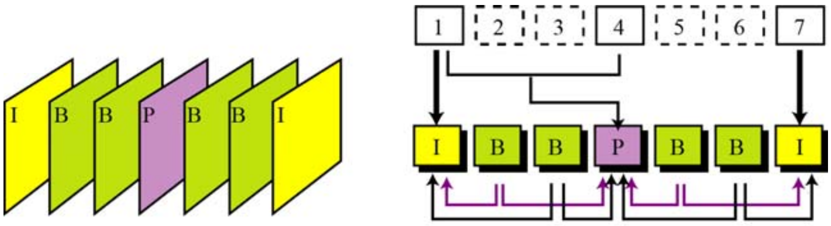
## Types of Frames

- I frame (intra-coded)
  - Coded without reference to other frames
- P frame (predictive-coded)
  - Coded with reference to a previous reference frame (either I or P)
  - Size is usually about 1/3rd of an I frame
- B frame (bi-directional predictive-coded)
  - Coded with reference to both previous and future reference frames (either I or P)
  - Size is usually about 1/6th of an I frame



## GOP (Group of Pictures)

- GOP is a set of consecutive frames that can be decoded without any other reference frames
- Usually 12 or 15 frames
- Transmitted sequence is not the same as displayed sequence
- Random access to middle of stream – Start with I frame




a. Frames b. Frame construction

## Things about Prediction

- Only use motion vector if a “close” match can be found
  - Evaluate “closeness” with MSE or other metric
  - Can’t search all possible blocks, so need a smart algorithm
  - If no suitable match found, just code the macroblock as an I-block
  - If a scene change is detected, start fresh
- Don’t want too many P or B frames in a row
  - Predictive error will keep propagating until next I frame
  - Delay in decoding



## Bitrate Allocation

- CBR – Constant BitRate
  - Streaming media uses this
  - Easier to implement
- VBR – Variable BitRate
  - DVD’s use this
  - Usually requires 2-pass coding
  - Allocate more bits for complex scenes
  - This is worth it, because you assume that you encode once, decode many times

## Evolution of MPEG

- MPEG-1
  - Initial audio/video compression standard
  - Used by VCD's
  - MP3 = MPEG-1 audio layer 3
  - Target of 1.5 Mb/s bitrate at 352x240 resolution
  - Only supports progressive pictures



## Evolution of MPEG

- MPEG-2
  - Current de facto standard, widely used in DVD and Digital TV
  - Ubiquity in hardware implies that it will be here for a long time
    - Transition to HDTV has taken over 10 years and is not finished yet
  - Different profiles and levels allow for quality control

# Evolution of MPEG

- MPEG-3
  - Originally developed for HDTV, but abandoned when MPEG-2 was determined to be sufficient
- MPEG-4
  - Includes support for AV “objects”, 3D content, low bitrate encoding, and DRM
  - In practice, provides equal quality to MPEG-2 at a lower bitrate, but often fails to deliver outright better quality
  - MPEG-4 Part 10 is H.264, which is used in HD-DVD and Blu-Ray