# The Video Data Type

## Coding & Compression Basics


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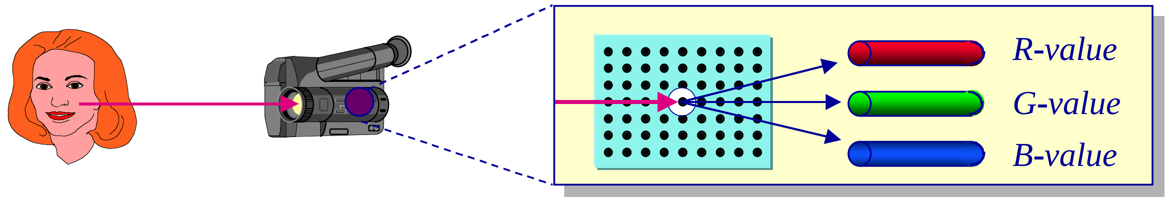
# The Video Data Type

## Outline

- What is video?
  - » Video components
  - » Representations of video signals
  - » Color spaces
- Digital Video
  - » Coding
- Compression basics
  - » Simple compression
  - » Interpolation-based techniques
  - » Predictive techniques
  - » Transforms
  - » Statistical techniques

# Video Basics
## The components of video

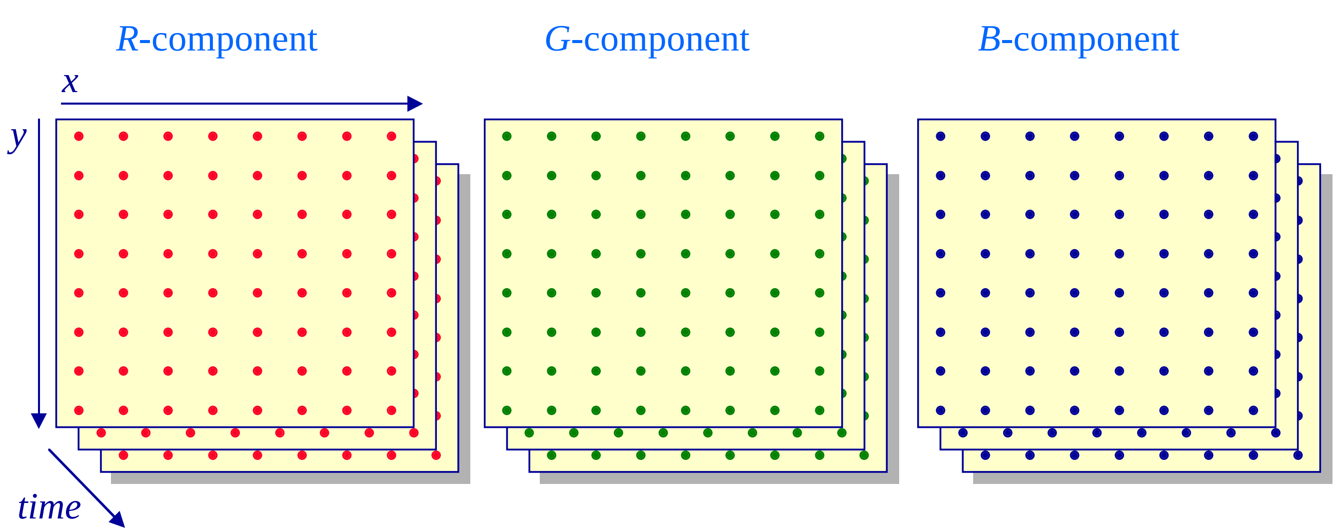



- Video deals with *absorbed* and *projected* light
  - » Cameras absorb light and monitors project light
- The primary colors in this domain are:
  - » red, green, and blue



# Video Basics
## The components of video transmission

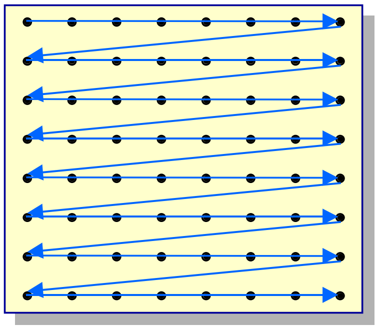
- Video is a multi-dimensional signal



# Video Basics

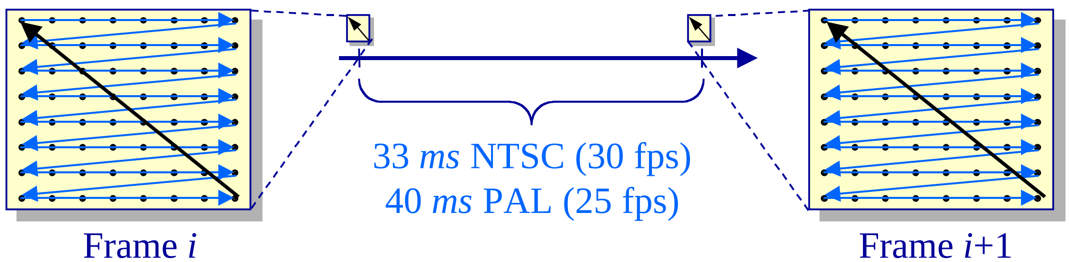
## Video as a 1-dimensional signal

- Representation of a 2-dimensional image



$(R, G, B)_{11}, (R, G, B)_{12}, (R, G, B)_{13}, \ldots, (R, G, B)_{row,\, col}$

- Representation of motion (3-dimensional images)






# Video Basics

## Resolution

- Television broadcast standards
  - » NTSC — 525 lines
  - » PAL — 625 lines
- Computer graphics standards
  - » VGA — 640x480
  - » SVGA — 1024x768
- Multimedia standards
  - » CIF — 352x288
  - » QCIF — 176x144
- Digital video standards
  - » CCIR 601 — 720x480
  - » HDTV — 1440x1152

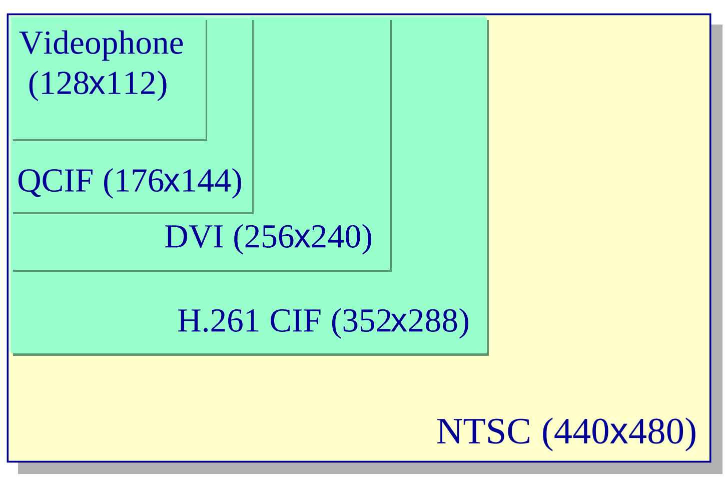



Image sizes
(in picture elements)

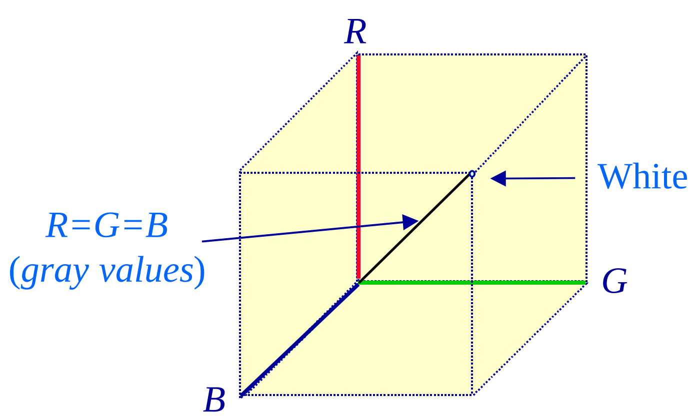
# Video Basics
## Color spaces

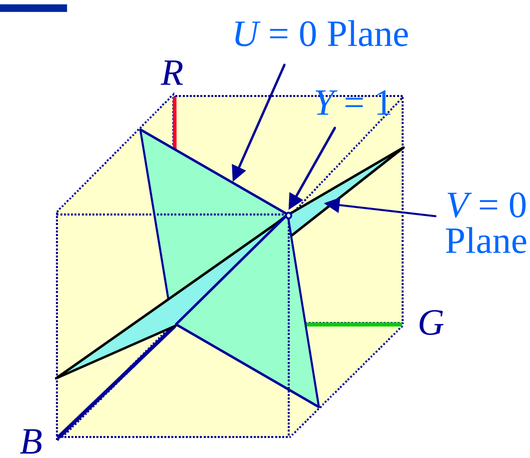
- *RGB* is not widely used for transmitting a signal between capture and display devices
  - » It's difficult to manage 3 separate inputs & outputs (and requires too much bandwidth)

- Composite formats are used instead
  - » Luminance ("*Y*") — the brightness of the monochrome signal
  - » Chrominance — the coloring information
  - » Chrominance is typically represented by two "color difference" signals:
    - ❖ "*U*" and "*V*" ("*hue* and *tint*") or
    - ❖ "*I*" and "*Q*" ("*saturation*" and "*color*")



# Video Basics
## Color spaces




- *NTSC* video
  - » $Y = 0.30R + 0.59G + 0.11B$
  - » $I = 0.60R - 0.28G - 0.32B$
  - » $Q = 0.21R - 0.52G + 0.31B$

- *PAL* video/Digital recorders
  - » $Y = 0.3R + 0.6G + 0.1B$
  - » $U = (B - Y) \times 0.493$
  - » $V = (R - Y) \times 0.877$

# Video Basics
## Digital video

- Sample an analog representation of video (*RGB* or *YUV*) & quantize
  - » Two dimensions of video are already discretized
  - » Sample in the horizontal direction according to the resolution of the media

- 8-bits per component per sample is common
  - » 24 bits per picture element (pixel)

- Storage/transmission requirements
  - » NTSC — 440 x 480 x 30 x 24 = $152 \times 10^6$ bits/sec (19 MB/s or 24 bits/pixel (bpp))



# The Video Data Type
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  - » Representations of video signals
  - » Color spaces

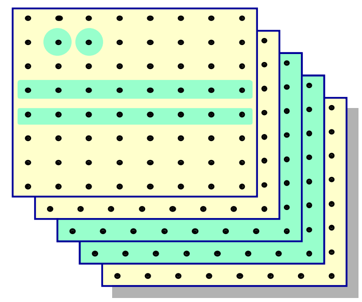
- Digital Video
  - » Coding

- Compression basics
  - » Simple compression
  - » Interpolation-based techniques
  - » Predictive techniques
  - » Transforms
  - » Statistical techniques

# Digital Video
## Compression Techniques

- Do we really need every “bit” of a video stream?
  - » Not if redundancy exists
  - » Not if we can’t perceive the effect of eliminating the bit

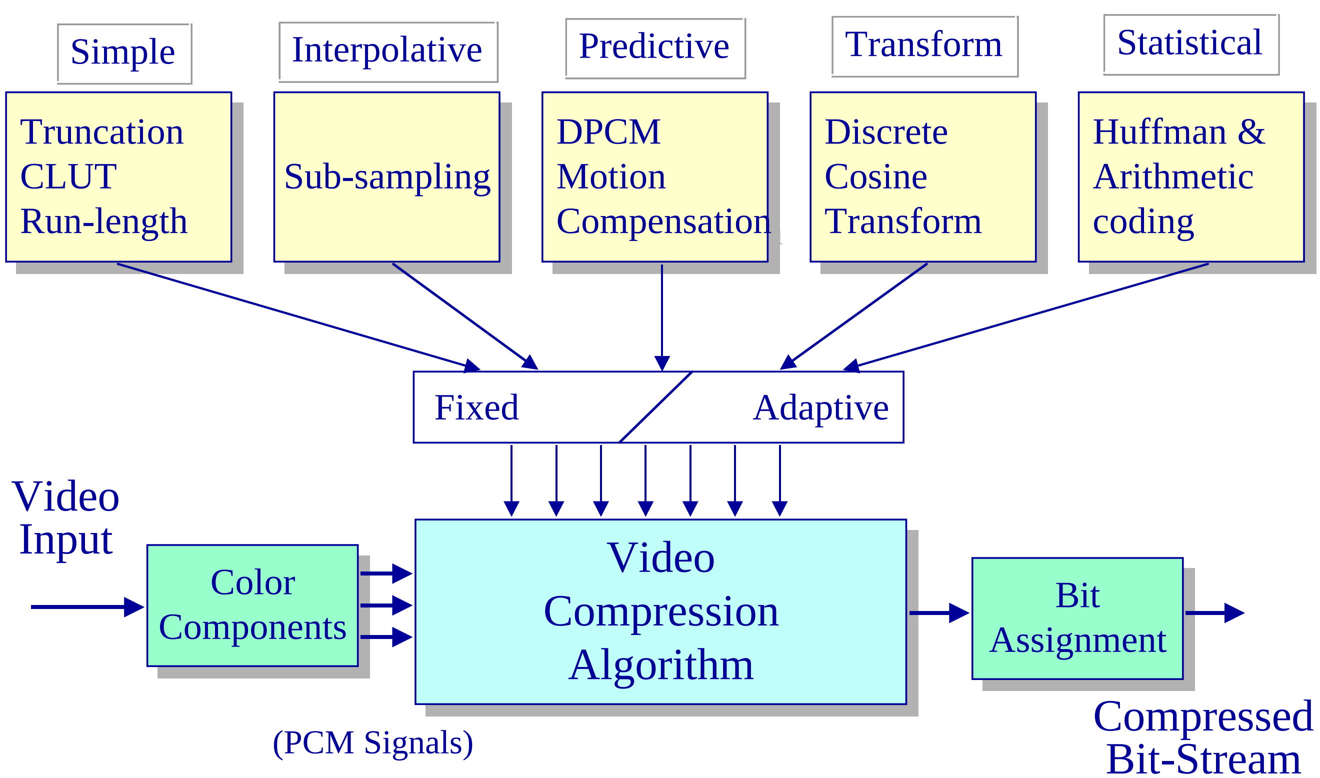
- Eliminating redundancy
  - » Spatial redundancy
  - » Temporal redundancy



- Eliminating imperceptible detail
  - » Coding
  - » Domain transformation



# Digital Video
## Compression Techniques




Adapted from Buford p.147

# Video Compression
## Issues

- Bandwidth requirements of resulting stream
  - » Bits per pixel (bpp)
- Image quality
- Compression/decompression speed
  - » Latency
  - » Cost
  - » Symmetry
- Robustness
  - » Tolerance of errors and loss
- Application requirements
  - » Live video
  - » Stored video



# Simple Image Compression
## Truncation

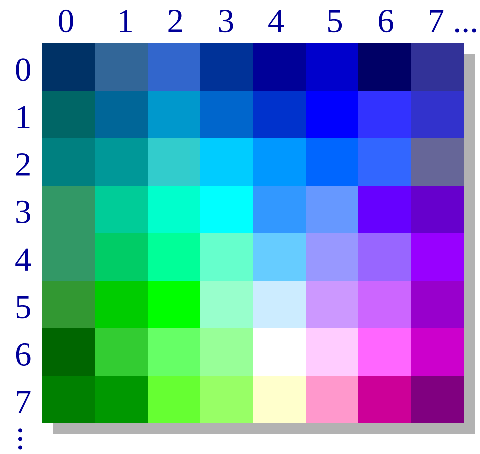
- Reducing the number of bits per pixel
  - » Throw away the least significant bits of each sample value
- Example
  - » Go from *RGB* at 8 bits/component sample (8:8:8) to 5 bits (5:5:5)
    - Go from 24 bpp to 15 bpp
    - This gives “acceptable results”
  - » Go from *YUV* at 8 bits/component sample 6:5:5 (16 bpp)
- Advantage — simple!

# Simple Compression Schemes

## Color-table lookup (CLUT)

- Quantize coarser in the color domain
  - » Pixel values represent indices into a color table
  - » Tables can be optimized for individual images
- Entries in color table stored at "full resolution" (*e.g.* 24 bits)
- Example:
  - » 8-bit indices (256 colors) gives

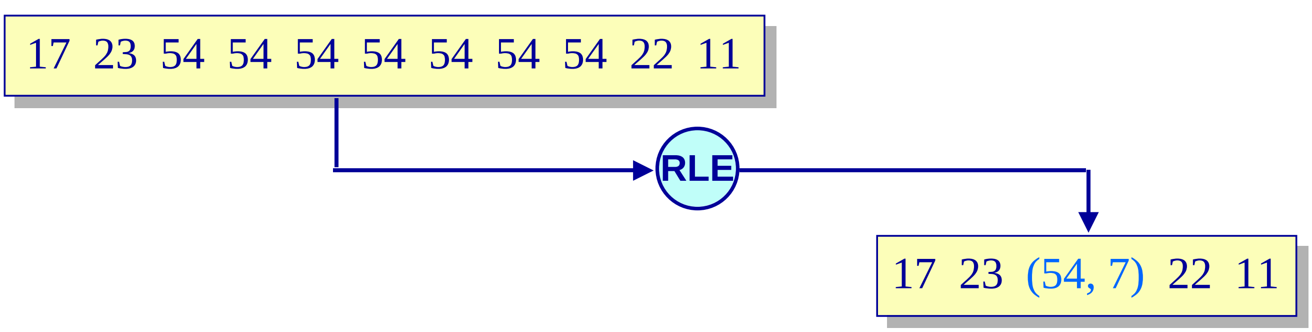
    $(440 \times 480) \times 8 + (24 \times 256) = 1.7 \times 10^6$ bits/sec






# Simple Compression Schemes

## Run-length encoding



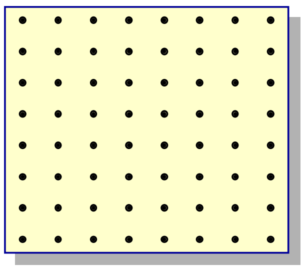

- Replace sequences of pixel components with identical values with a pair (*value*, *count*)
- Works well for computer-generated images, cartoons. works less well for natural video
- Also works well with CLUT encoded images

  (*i.e., multiple techniques may be effectively combined*)

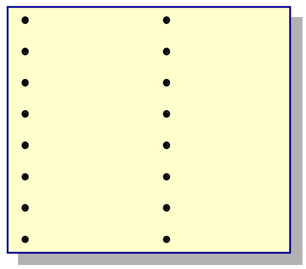
# Interpolative Compression Schemes

## Color sub-sampling

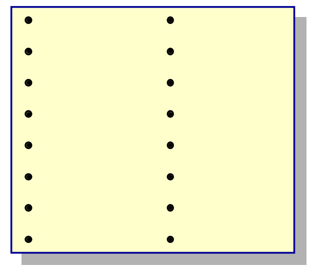
- Do not acquire chrominance component values at all sampling points
  - » Humans have poor acuity for color changes
  - » *UV* and *IQ* components were defined with this in mind
- <u>Example</u>: Color representation in digital tape recorders
  - » Subsampling by a factor of 4 horizontally is performed



*Y* component



*U* component



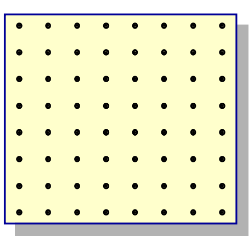
*V* component



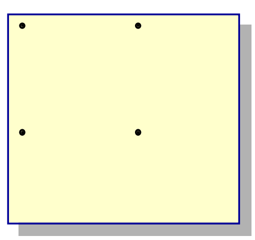
# Interpolative Compression Schemes

## Color sub-sampling

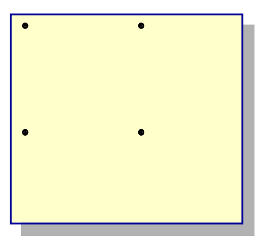
- Subsampling by a factor of 4 horizontally & vertically



*Y* component



*U* component



*V* component

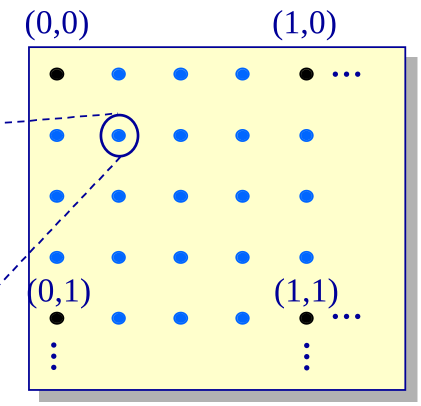
- Interpolating between samples provides “excellent” results
  - » Chrominance still sampled at 8 bpp

# Interpolative Compression Schemes

## Color sub-sampling

- Intermediate pixels either take on the value of nearest sampling point or their value is computed by interpolation
- Bi-linear interpolation:

$U(1, 1) = U(0,0) \times 0.75 + U(1,0) \times 0.25 + U(0,1) \times 0.75 + U(1,1) \times 0.25$

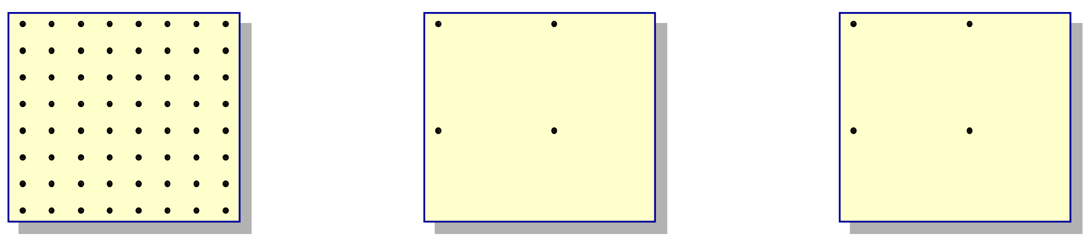



Sub-sampled
*U* or *V* component



# Interpolative Compression Schemes

## Color sub-sampling



*Y* component | *U* component | *V* component

- Storage/transmission requirements reduction:
  - » Within a 4x4 pixel block:

$$\text{bpp} = \frac{(8 \text{ bpp luminance}) \times 16 \text{ samples} + (8 \text{ bpp chrominance}) \times 2}{16}$$

$$= 9$$

  - » A 62.5% reduction overall

# Predictive Compression Schemes

## Exploiting spatial & temporal redundancy

- Adjacent pixels are frequently similar
  - » Do pixel-by-pixel DPCM compression
    - Leads to smearing of high-contrast edges
  - » ADPCM — a little better, a little worse
    - Introduces "edge quantization" noise
- Motion Estimation — If the future is the similar to the past, encode only the difference between frames
  - » This assumes we can store a previous frame to compare with a future one

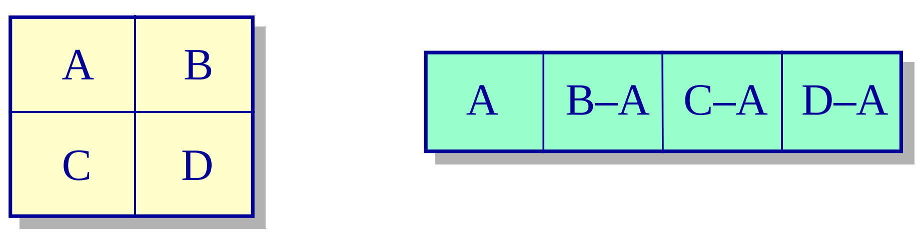


# Transform-Based Compression

## Exploiting redundancy in other domains

- A simple linear transformation

2 x 2 array of pixels 1-D array of differences

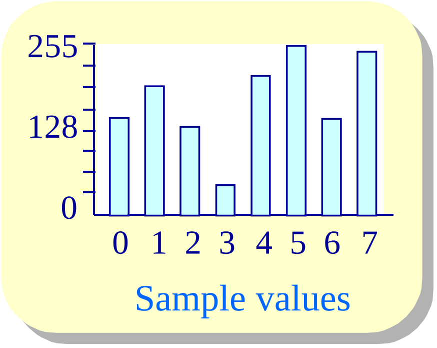


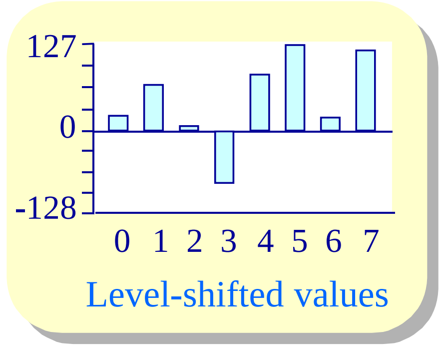

  - » Encode differences with less precision
- Storage savings
  - » Original array: 4 pixels x 8 bpp = 32 bits
  - » Transformed array: 8 bits + (3 pixels x 4 bpp) = 20 bits

# Transform-Based Compression

## The Discrete Cosine Transform (DCT)

- A transformation into the frequency domain
- Example: 8 adjacent pixel values (*e.g.*, luminance)



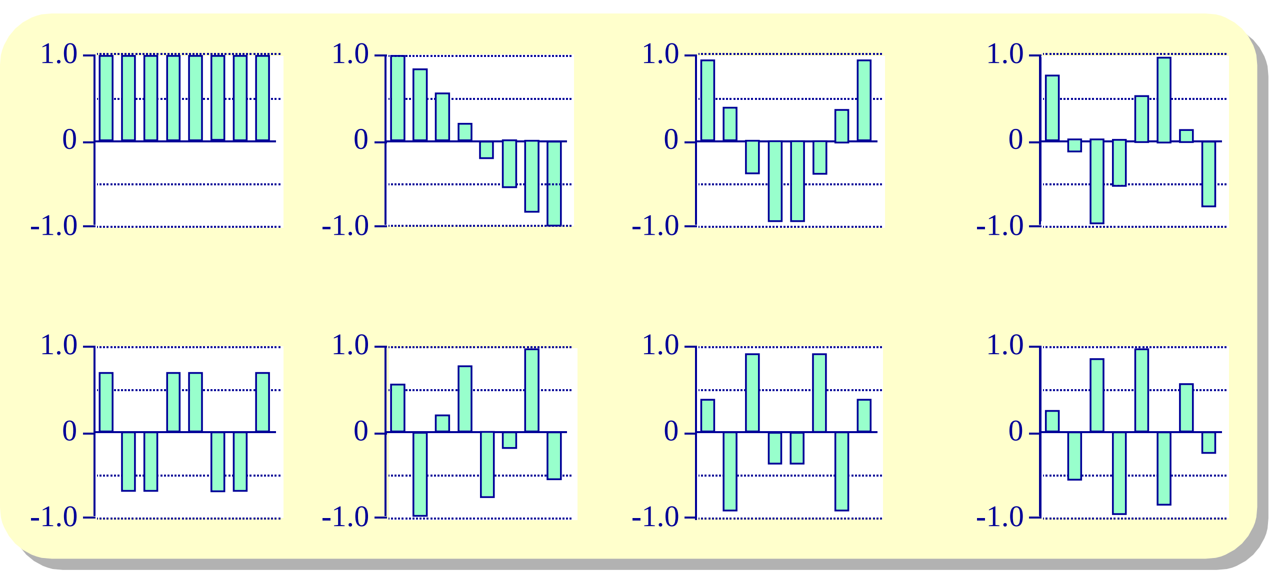

- What is the most compact way to represent this signal?



# Transform-Based Compression

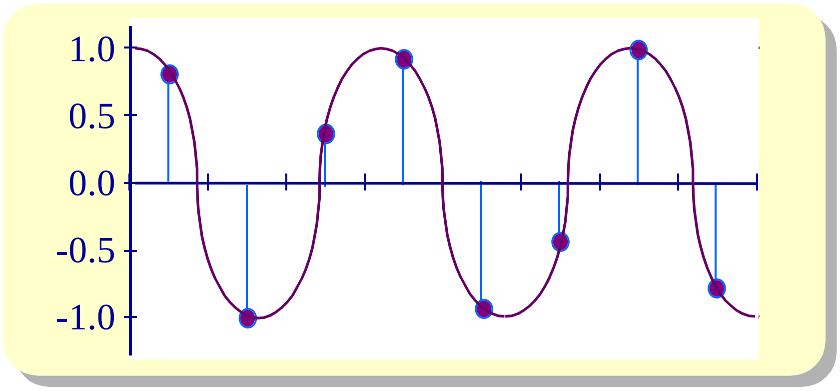
## The Discrete Cosine Transform (DCT)

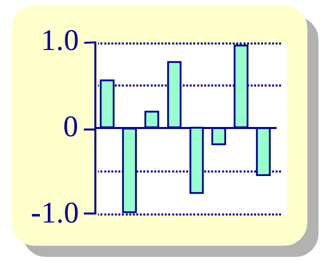
- Represent the signal in terms of a set of *cosine basis functions*



# Transform-Based Compression

## The Discrete Cosine Transform (DCT)



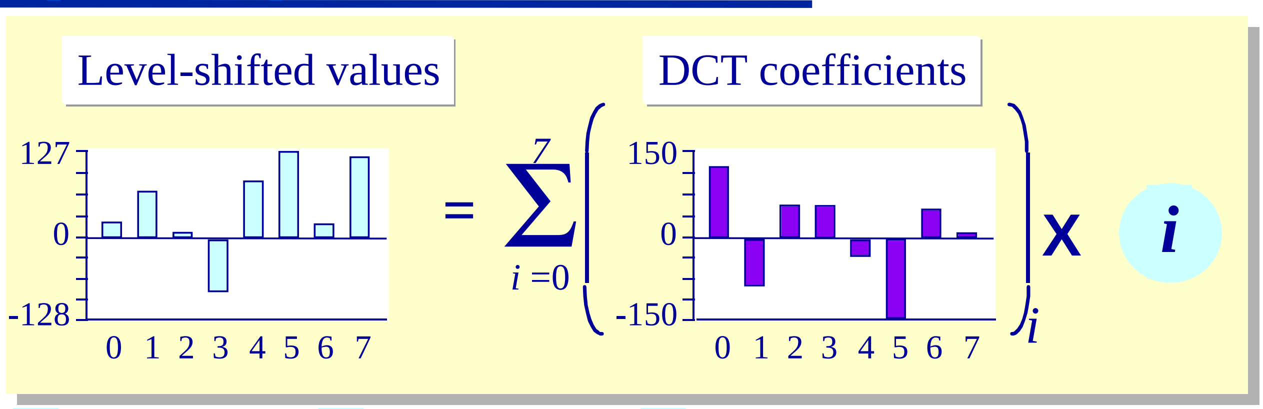

Sampled 2.5 Hz cosine wave

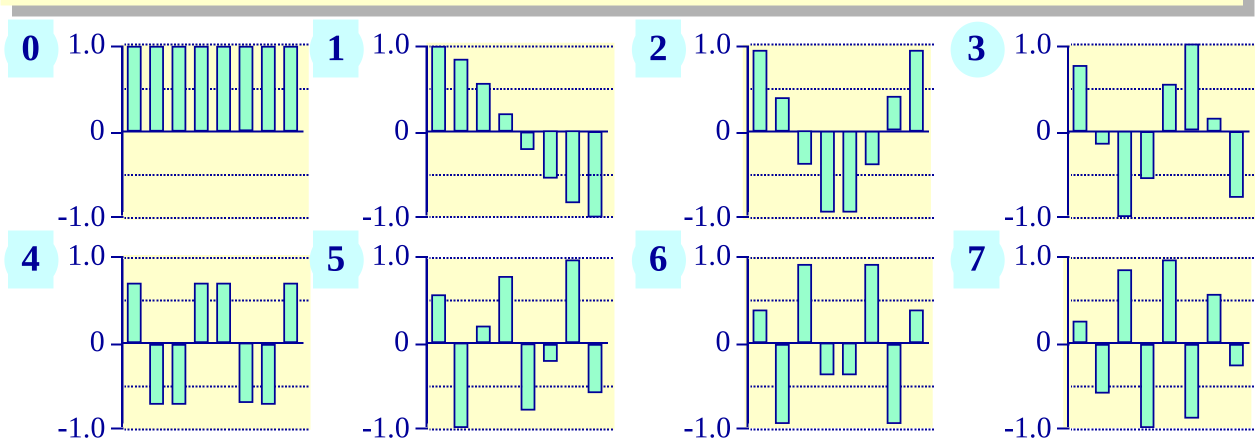
- The basis functions derive from sampling cosine functions of increasing frequency
  - » From 0-3.5 Hz
  - » Basis functions sampled at 8 discrete points



# The Discrete Cosine Transform

## Represent input as a sum of scaled basis functions



# Transform-Based Compression

## The Discrete Cosine Transform (DCT)

- The 1-dimensional transform:

$$F(\mu) = \frac{C(\mu)}{2} \sum_{x=1}^{7} f(x) \cos \frac{(2x+1)\mu\pi}{16}$$

  - » $F(\mu)$ is the DCT coefficient for $\mu = 0..7$
  - » $f(x)$ is the $x^{th}$ input sample fot $x = 0..7$
  - » $C(\mu)$ is a constant (equal to $2^{-0.5}$ if $\mu = 0$ and 1 otherwise)

- The 2-dimensional (spatial) transform:

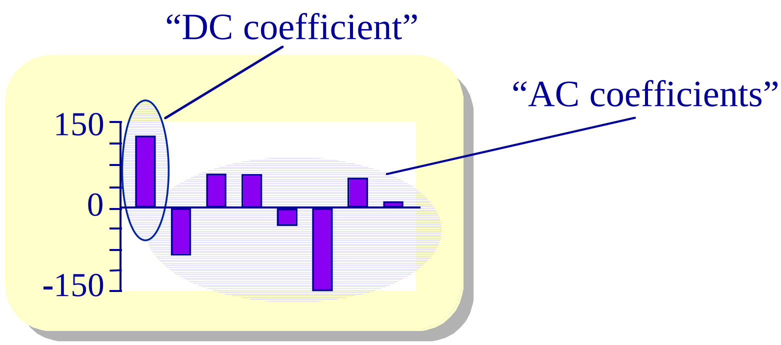
$$F(\mu,\nu) = \frac{C(\mu)}{2}\frac{C(\nu)}{2} \sum_{y=1}^{7}\sum_{x=1}^{7} f(x,y) \cos \frac{(2x+1)\mu\pi}{16} \cos \frac{(2y+1)\nu\pi}{16}$$



# Transform-Based Compression

## The Discrete Cosine Transform (DCT)

- DCT coefficients encode the spatial frequency of the input signal
  - » DC coefficient — zero spatial frequency (the "average" sample value)
  - » AC coefficients — higher spatial frequencies



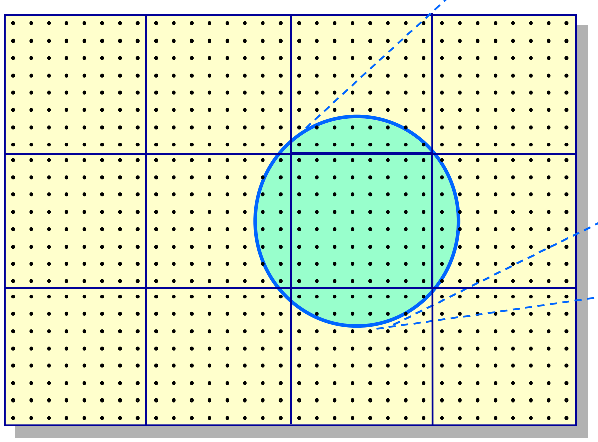

- Claim: Higher frequency coefficients will be zero and can be ignored

# Transform-Based Compression

## The two-dimensional DCT

- Apply the DCT in *x* and *y* dimensions simultaneously to 8x8 pixel blocks
  - » Code coefficients individually with fewer bits

Video Frame



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 172 | -18 | 15 | -8 | 23 | -9 | -14 | 19 |
| 21 | -34 | 24 | -8 | -10 | 11 | 14 | 7 |
| -9 | -8 | -4 | 6 | -5 | 4 | 3 | -1 |
| -10 | 6 | -5 | 4 | -4 | 4 | 2 | 1 |
| -8 | -2 | -3 | 5 | -3 | 3 | 4 | 6 |
| 4 | -2 | -4 | 6 | -4 | 4 | 2 | -1 |
| 4 | -3 | -4 | 5 | 6 | 3 | 1 | 1 |
| 0 | -8 | -4 | 3 | 2 | 1 | 4 | 0 |

DCT Coefficients



# Statistical Compression

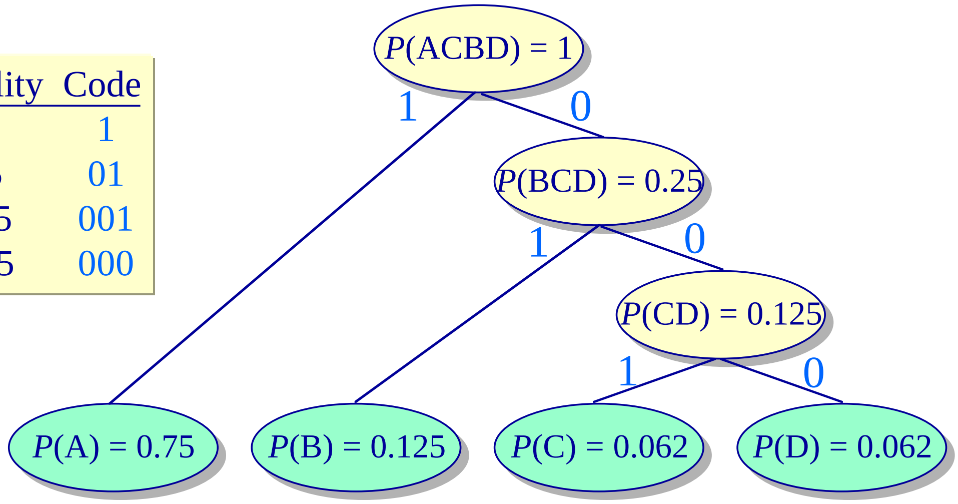
## Huffman coding

- Exploit the fact that not all sample values are equally likely
  - » Samples values are non-uniformly distributed
  - » Encode “common” values with fewer bits and less common values with more bits
- Process each image to determine the statistical distribution of sample values
  - » Generate a *codebook* — a table used by the decoder to interpret variable length codes
  - » Codebook becomes part of the compressed image

# Statistical Compression

## Huffman coding

| Symbol | Probability | Code |
|---|---|---|
| A | 0.75 | 1 |
| B | 0.125 | 01 |
| C | 0.0625 | 001 |
| D | 0.0625 | 000 |




- Order all possible sample values in a binary tree by combining the least likely samples into a sub-tree
- Label the branches of the tree with 1's and 0's
  - » Huffman code is the sequence of 1's and 0's on the path from the root to the leaf node for the symbol