VC 13/14 – T16
Video Compression

Mestrado em Ciência de Computadores

Mestrado Integrado em Engenharia de Redes e Sistemas Informáticos

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Outline

- The need for compression
- Types of redundancy
- Image compression
- Video compression

Topic: The need for compression

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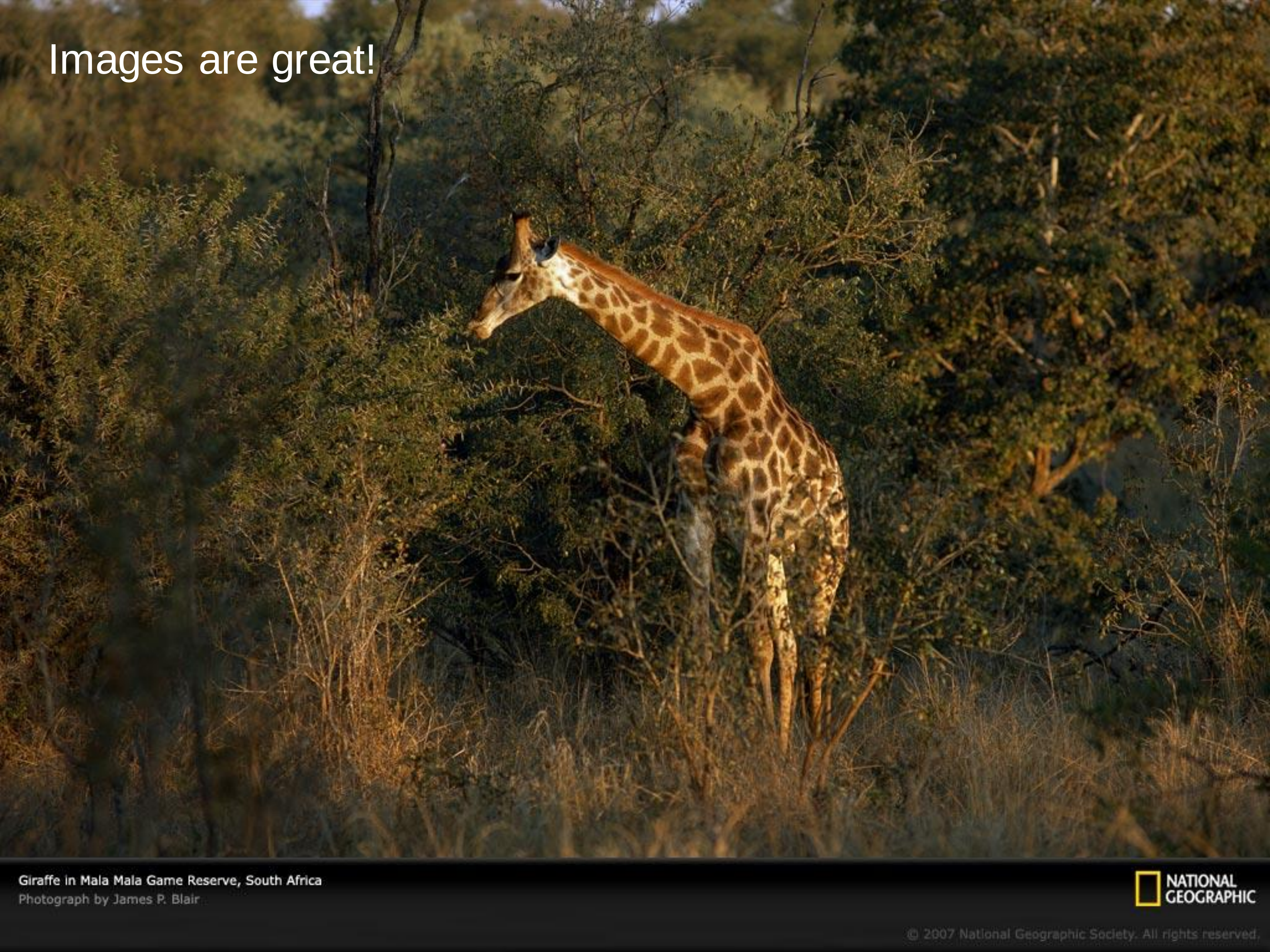
- Types of redundancy
- Image compression
- Video compression

Images are great!



But...

Images need storage space...

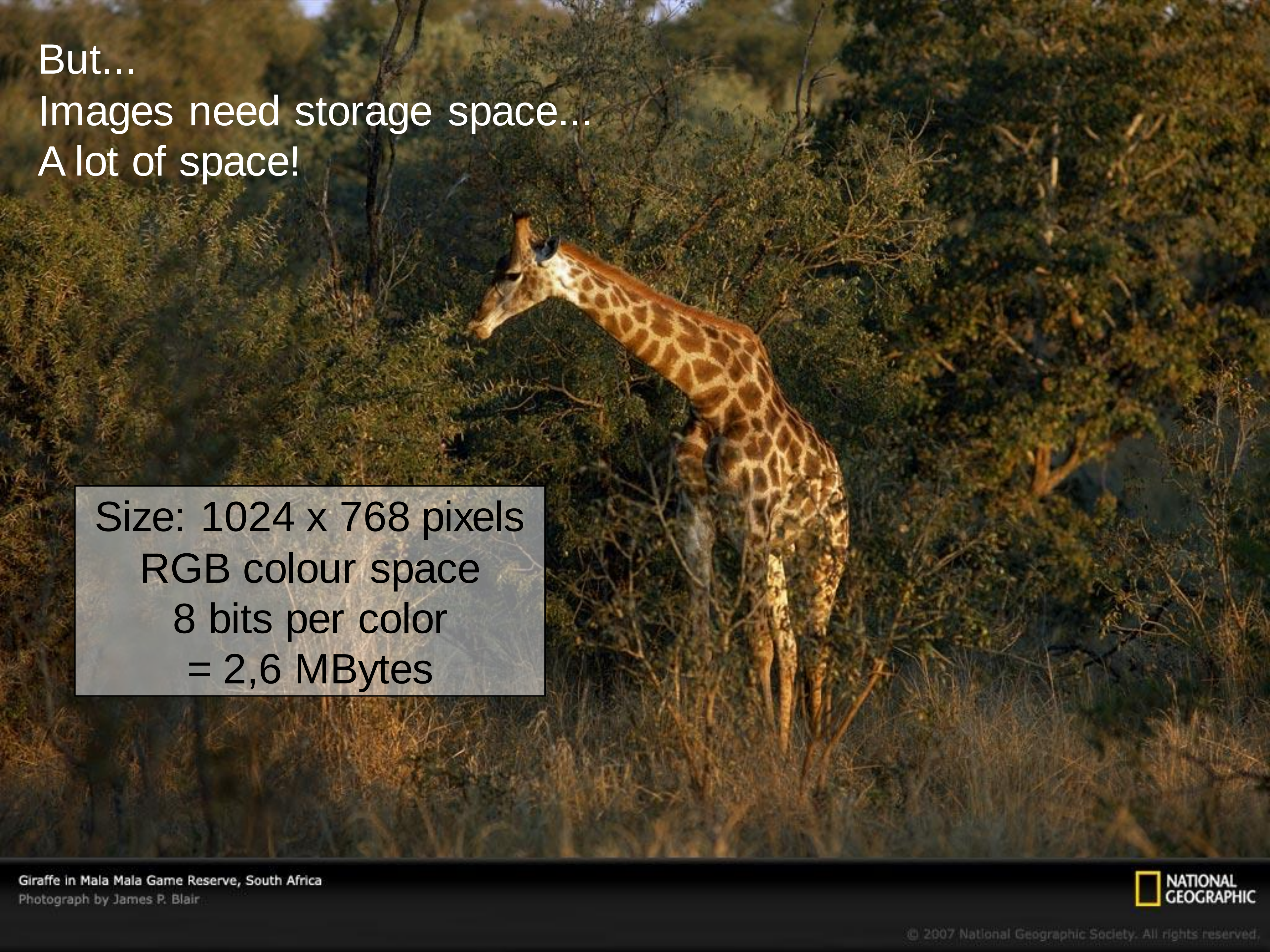
A lot of space!

Size: 1024 x 768 pixels

RGB colour space

8 bits per color

= 2,6 MBytes



What about video?

- VGA: 640x480, 3 bytes per pixel -> 920KB per image.
- Each second of video: 23 MB
- Each hour of vídeo: 83 GB

The death of Digital Video

What if... ?

- We exploit redundancy to compress image and video information?
  - Image Compression Standards
  - Video Compression Standards
- "Explosion" of Digital Image & Video
  - Internet media
  - DVDs
  - Digital TV
  - ...

Compression

- Data compression
  - Reduce the quantity of **data** needed to store the same **information**.
  - In computer terms: Use fewer **bits**.
- How is this done?
  - Exploit data **redundancy**.
- But don't we lose information?
  - Only if you want to...

Types of Compression

- Lossy
  - We do not obtain an exact copy of our compressed data after decompression.
  - Very high compression rates.
  - Increased degradation with sucessive compression / decompression.
- Lossless
  - We obtain an exact copy of our compressed data after decompression.
  - Lower compression rates.
  - Freely compress / decompress images.

It all depends on what we need...

Topic: Types of redundancy

- The need for compression
- Types of redundancy
- Image compression
- Video compression

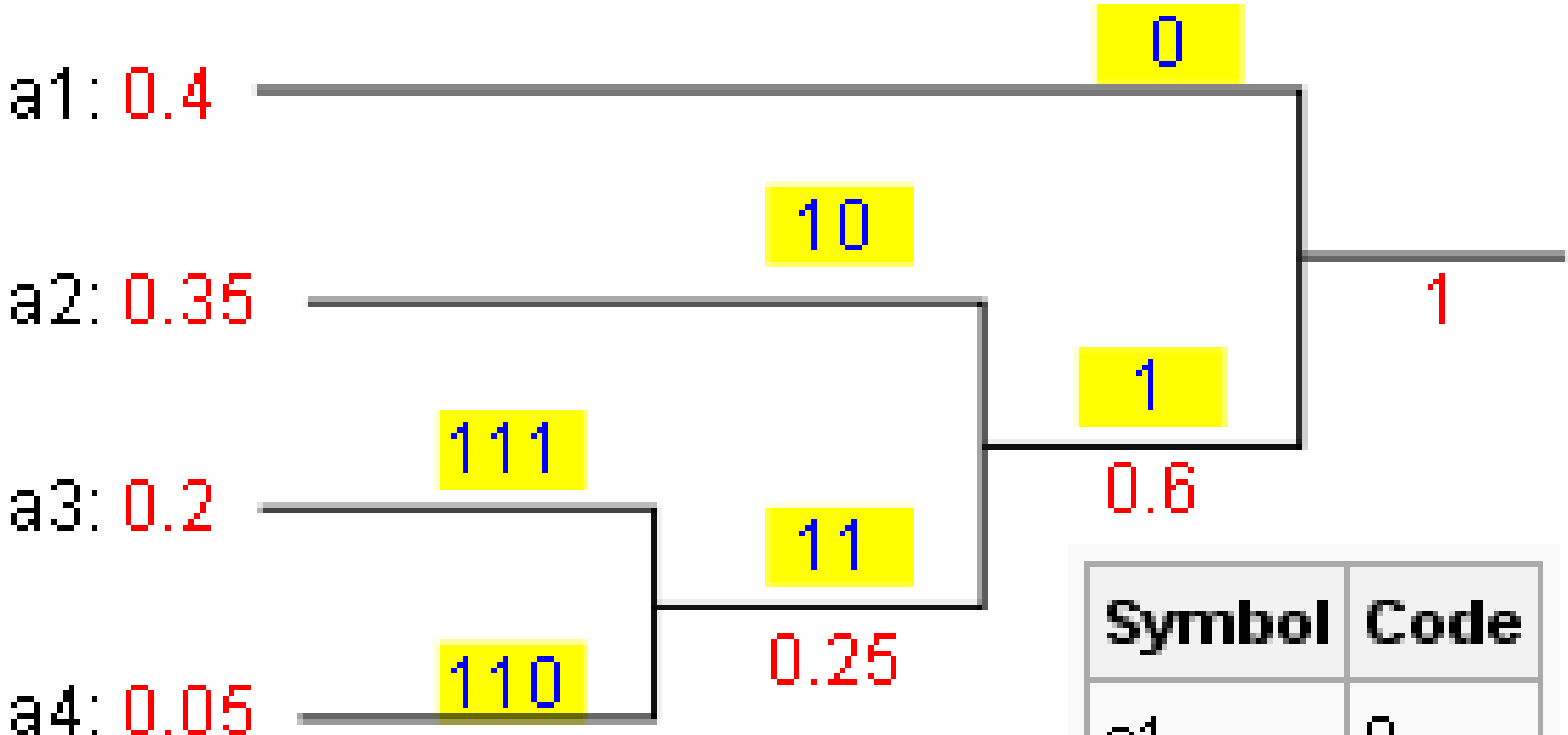
Coding Redundancy

- Information Theory
  - The most common values should be encoded with fewer bits.
- Huffman coding
  - Smallest possible number of code symbols per source symbols.
  - Lossless.
- LZW coding
  - Creates additional values for common sequences of values (e.g. sequence of black pixels).
  - GIF, TIFF, PDF.
  - Exploits the spatial redundancy of images!

Huffman Coding

- Developed by David A. Huffman while he was a Ph.D. student at MIT.
  - Variable-length code.
  - Entropy encoding algorithm.
- Optimal for a symbol-by-symbol coding.
- Lossless.

http://en.wikipedia.org/wiki/Huffman_coding



Symbol	Code
a1	0
a2	10
a3	111
a4	110

Normal representation: 2 bits/symbol
Entropy of the source: 1.73 bits/symbol
Huffman code: 1.83 bits/symbol

Spatial Redundancy

What about this one?

How to exploit this?

- Correlation between neighboring pixels.
  - E.g. A white line can be coded with two numbers: [nr. Pixels; colour].
- Mathematics:
  - Lossless
    - LZW Coding – GIF
    - ...
  - Lossy
    - The DCT Transform – JPEG
    - ...

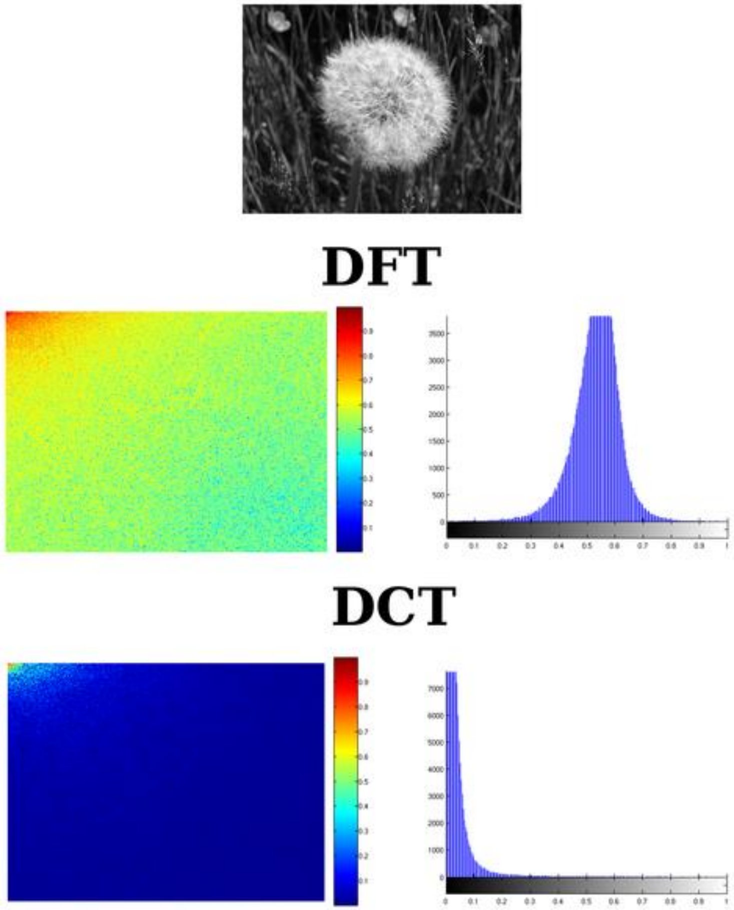
LZW Coding (Lempel-Ziv-Welch)

- In a nutshell:
  - Uses a *string translation table*.
  - Maps *fixed length codes* to *strings*.
- Why is this great for images?
  - ‘Imagine’ pixels as chars.
  - Common sequences of pixels are mapped by a single code.
  - How many codes are needed to represent a white line?

http://en.wikipedia.org/wiki/LZW

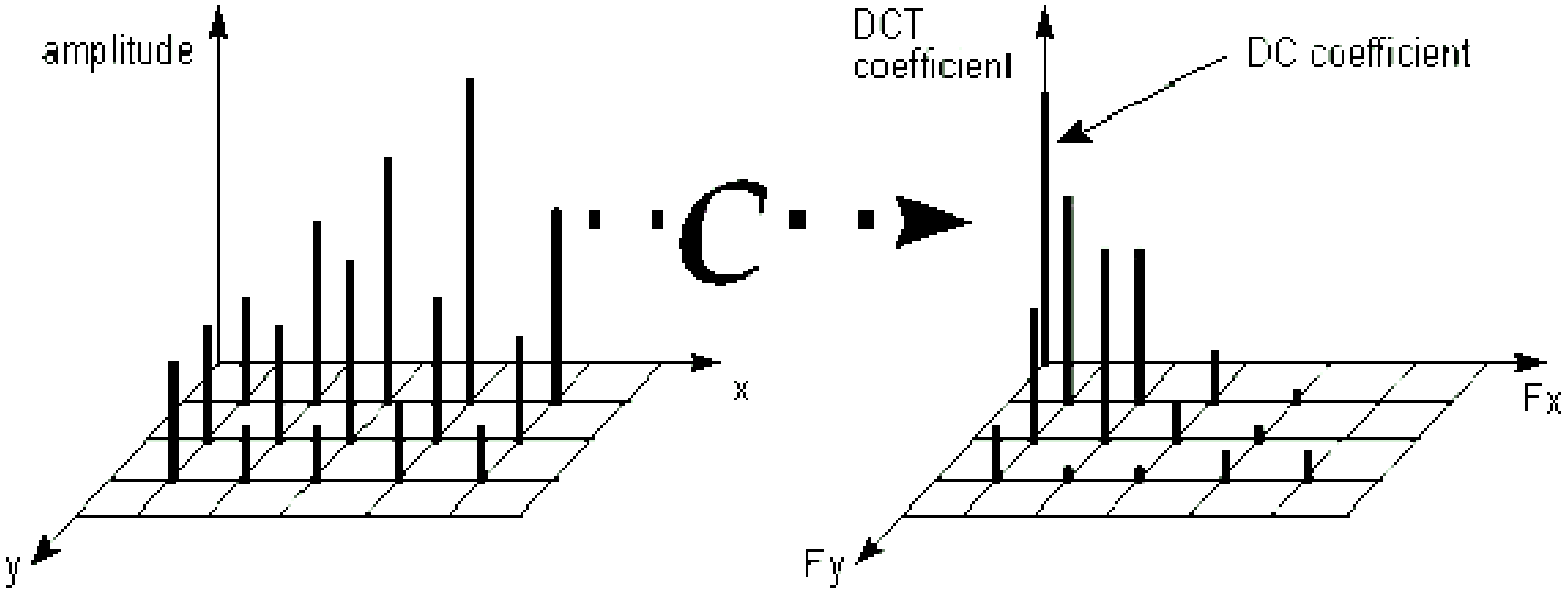
Discrete Cosine Transform (DCT)

- Can be seen as a ‘cut-down’ version of the DFT:
  - Use only the ‘real’ part but...
  - Has double the resolution so...
  - It has the same number of coefficients.
- Why do we use it?

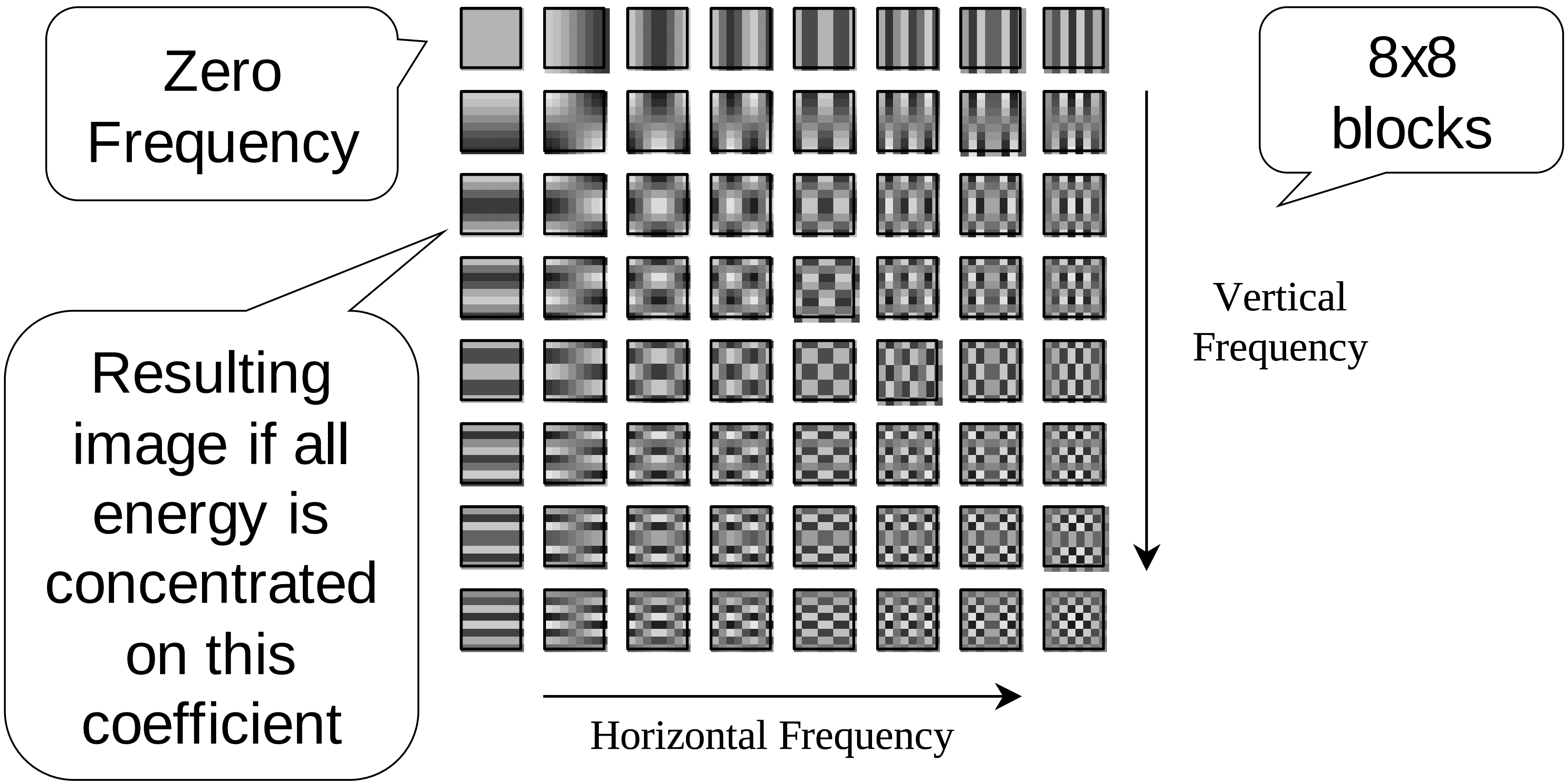


Why DCT?

- Energy ‘compacting potential’ superior to DFT.

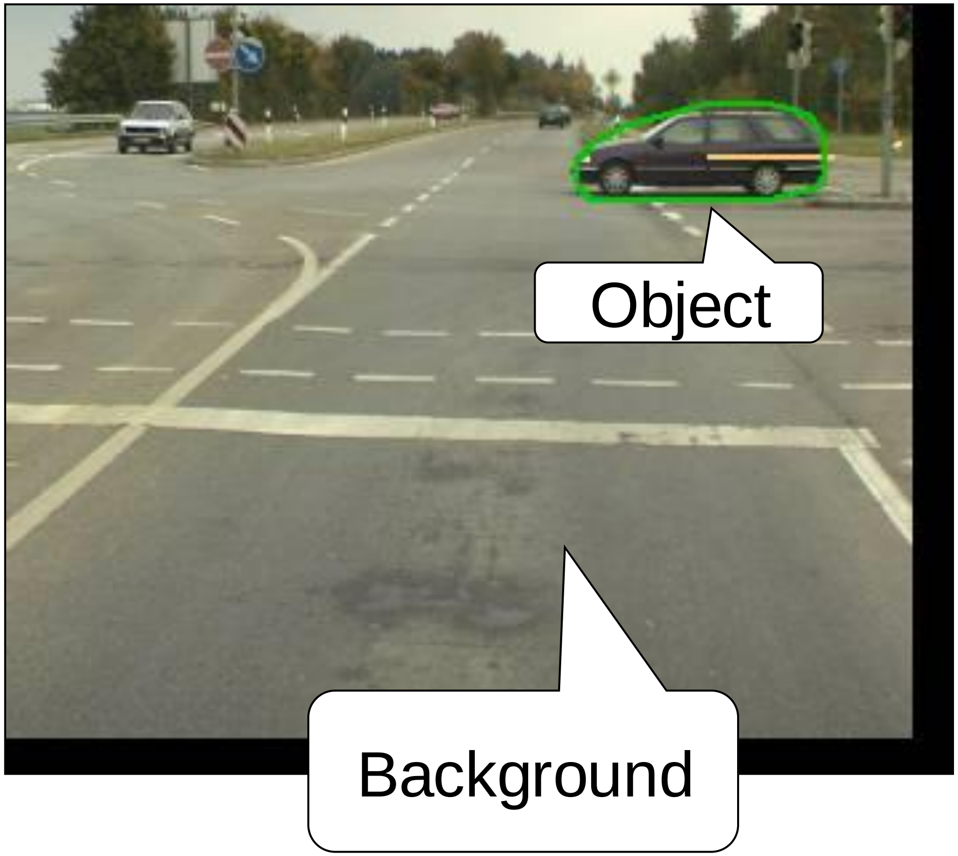


Visual significance of coefficients



Temporal redundancy

- Consecutive images of a video stream do not vary much.
  - Some areas don't change at all (background).
  - Others only change their spatial location (moving objects).

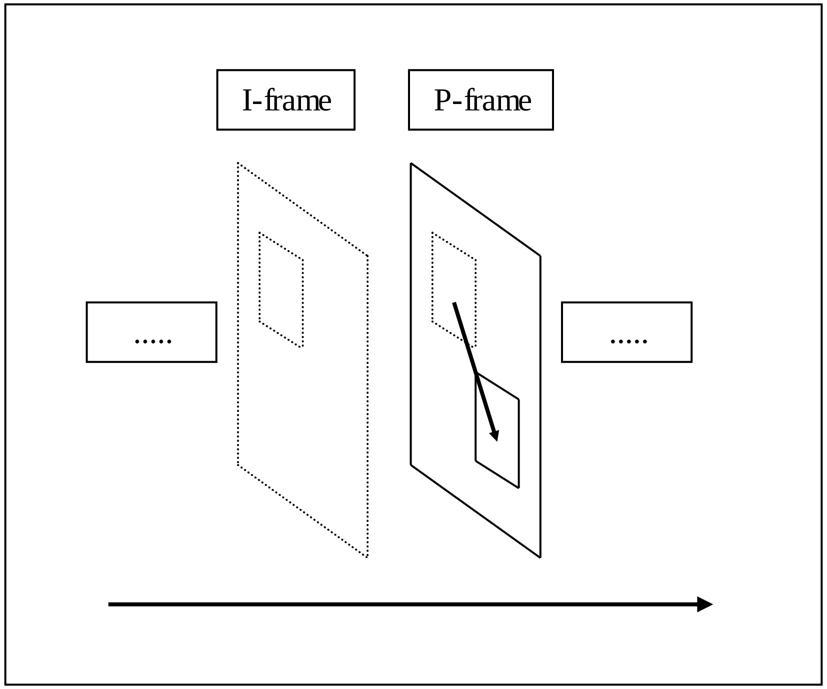


How do we exploit this?

- Send image differences
  - Consecutive images are very similar.
  - **Difference images** are spatially much more redundant than real images.
  - Exploit spatial redundancy of difference images!
- Motion vectors
  - What if the camera moves?
  - What if objects move?
  - Use **motion estimation** before calculating the difference image!

Motion estimation

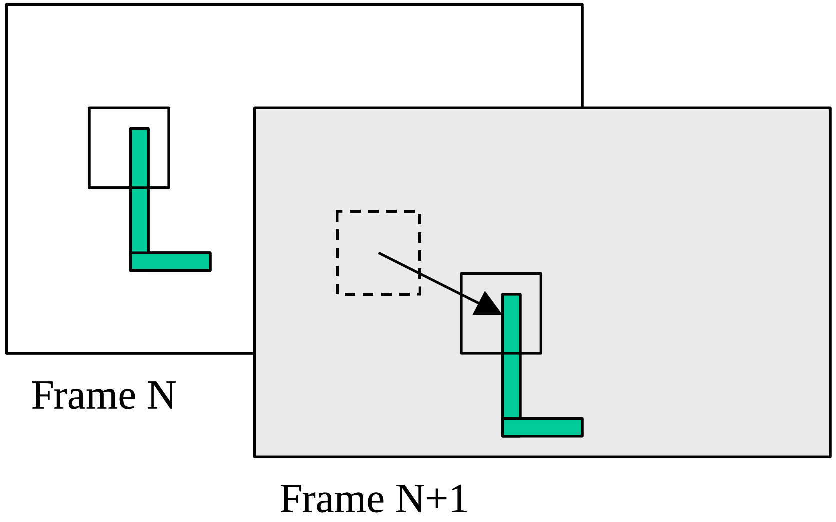
- Tries to find where an area of the image was in a previous image.
- Objective:
  - Minimize the difference between these two blocks.
- In fact:
  - We don't really care whether this is the same object or not...



Obtains **Motion Vectors**

Block Matching

- Search for a similar block in a neighboring region
  - Full search is too expensive. Variations: 3SS [Koga81], LogS [JJ81], N3SS [Li94], 4SS [PM96],...
  - Various cost functions used: MAD, MSD, CCF, PDC,...
- Noisy approximation to optical flow.
- Aperture and 'blank wall' problems.
- Confidence measures?

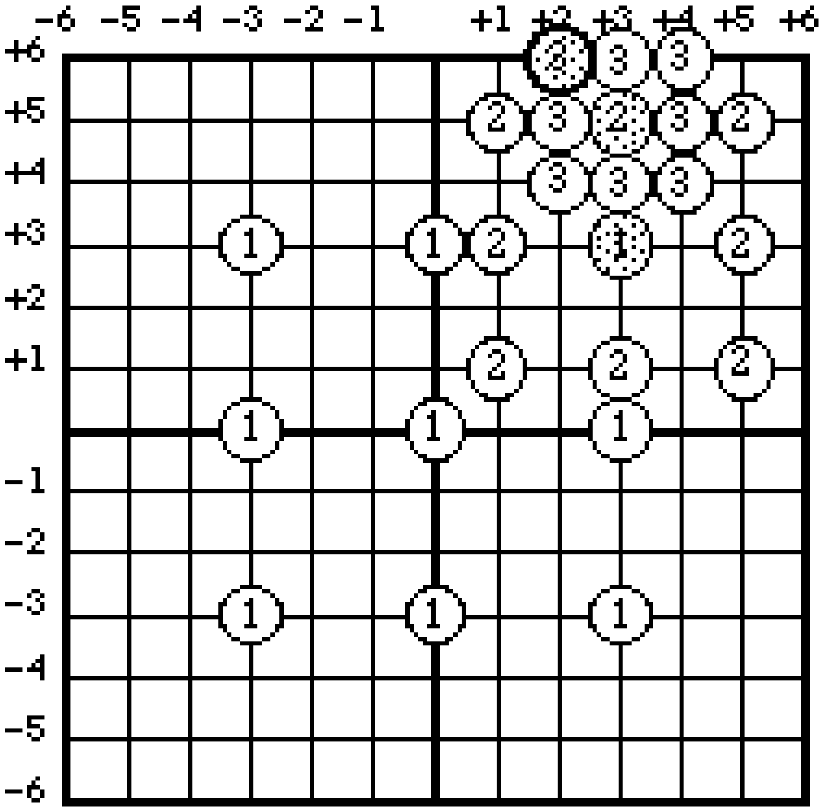


$$MAD(dx,dy) = \frac{1}{mn} \sum_{i=-n/2}^{n/2} \sum_{j=-m/2}^{m/2} \left| F(i,j) - G(i+dx, j+dx) \right|$$

$$MSD(dx,dy) = \frac{1}{mn} \sum_{i=-n/2}^{n/2} \sum_{j=-m/2}^{m/2} \left[F(i,j) - G(i+dx, j+dx) \right]^2$$

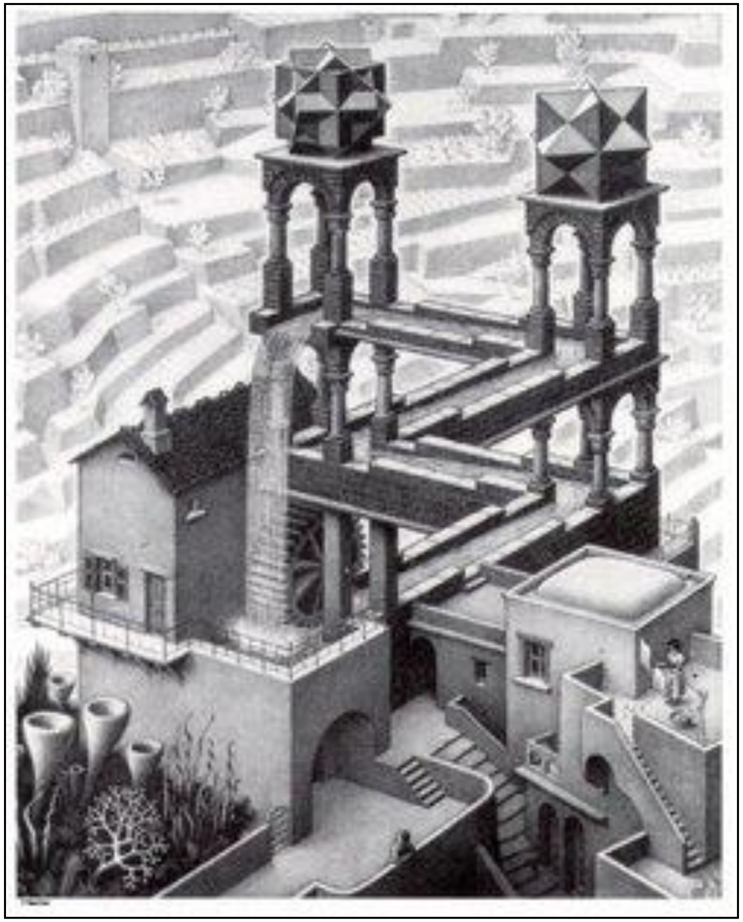
Three-Step Search (3SS)

- Algorithm
  - Test 8 points around the centre.
  - Choose 'lowest cost'.
  - Test 8 points around the new point with a lower step.
  - Etc...
- Very popular
  - Fast.
  - Moderate accuracy.
  - Easy to implement in hardware.



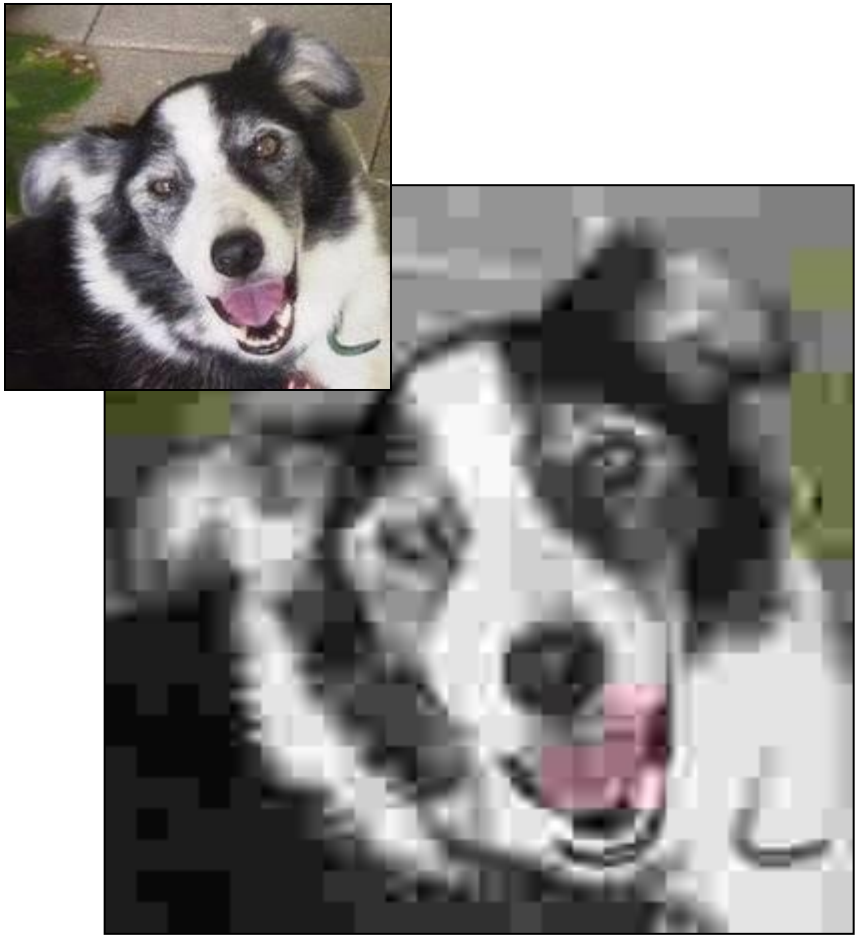
Psicovisual redundancy

- Human visual system
  - Different sensitivity to different information.
- Human processing
  - We only see some parts of the image.
  - Our brain completes the rest.



Human sensitivity

- We notice errors in homogenous regions.
  - Low frequencies.
- We notice errors in edges.
  - High frequencies.
- We don't notice noise in textured areas.
  - Medium frequencies.



Topic: Image compression

- The need for compression
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Lossless Compression

- Some types of images are not adequate for lossy compression.
  - Logos
  - Text
  - Medical images (??)
  - Etc.
- Our sensitivity to errors in these situations is too high.

Graphics Interchange Format (GIF)

- Lossless.
- 8 bpp format.
- 256 colour palette.
- LZW data compression.
- Popular for logos, text and simple images.
- Allows animations.

http://en.wikipedia.org/wiki/Image:Rotating_earth_%28large%29.gif

Lossy Compression

- Acceptable for most real images and situations.
- Very popular: JPEG.
- We can control the level of compression vs. Quality of the resulting image.
- How do we do this?

Lossy Image Compression

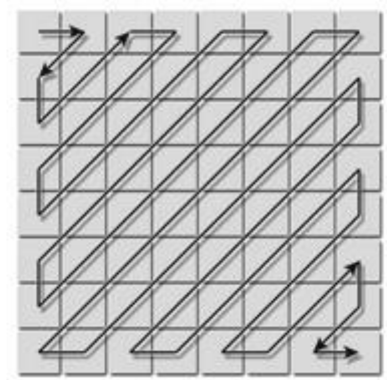
- Most popular: JPEG
  - Colour space: YCbCr
  - Colour less important than intensity.
  - DCT.
  - Quantization.
  - *Zig-Zag Run-Length Huffman encoding*

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

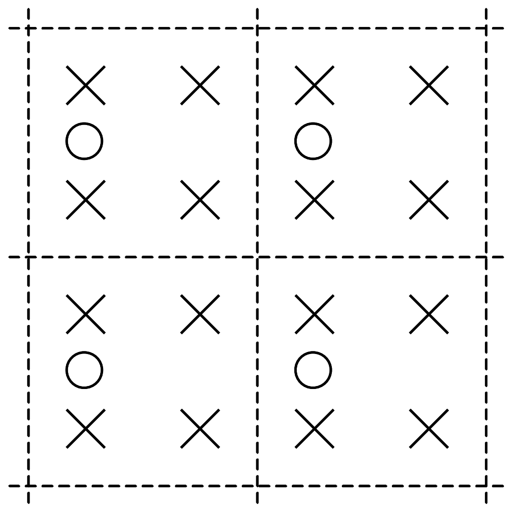
DCT

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

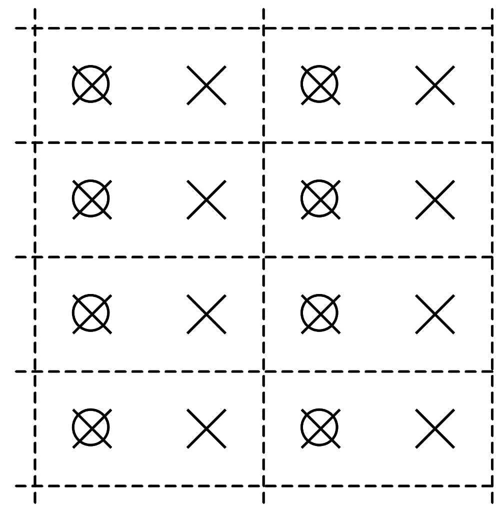
Zig-Zag
RLE



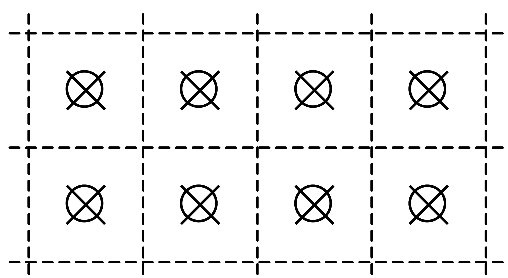
Chroma Format



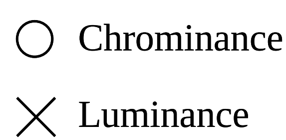
4:2:0 Chroma Format



4:2:2 Chroma Format

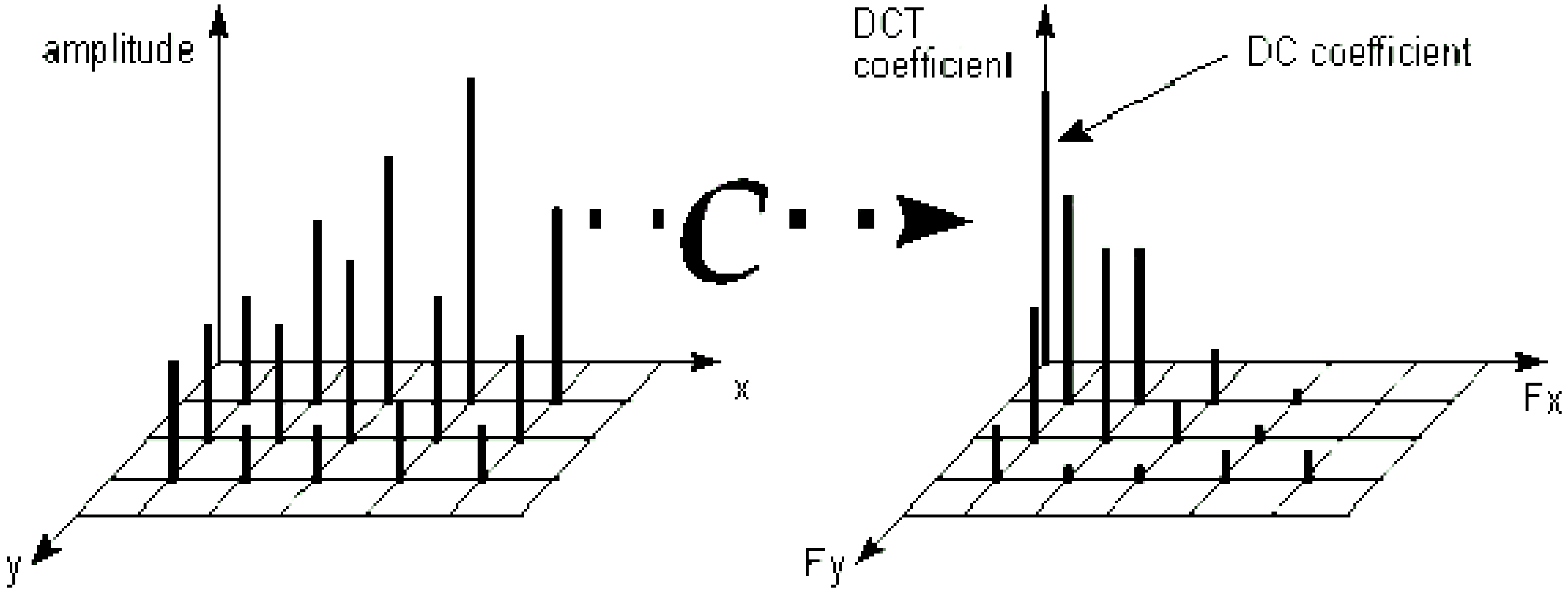


4:4:4 Chroma Format



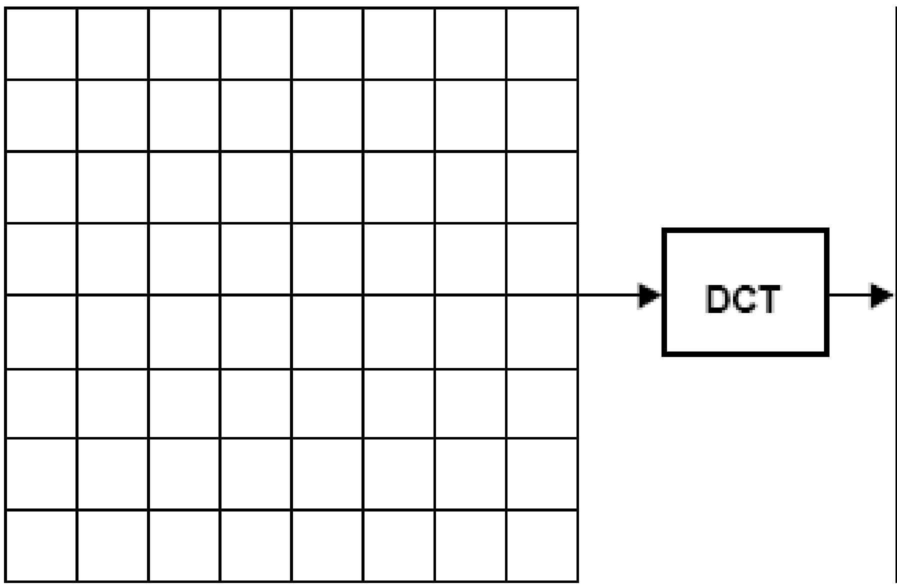
Psico-visual redundancy

DCT



Concentrate energy into a smaller number of coefficients

Quantization



DC	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

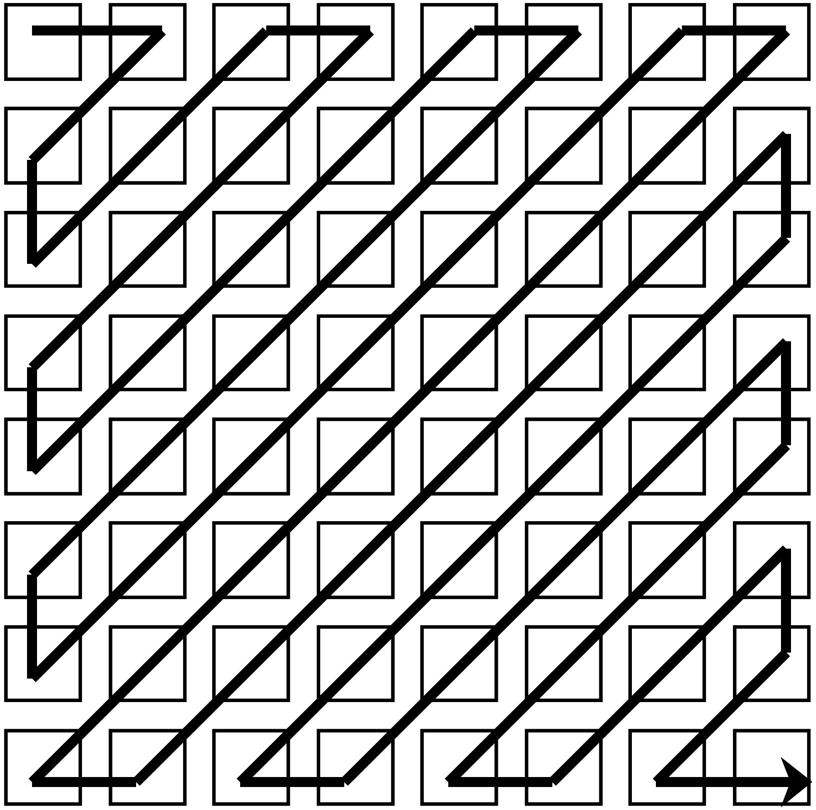
Increasing vertical frequency

Increasing horizontal frequency

Lossy Process!

Give higher importance to low spatial frequencies

Zig-Zag scanning



Create long sequences of zeros – **Huffman Coding**

Considerations

- We can control compression via a **quantization factor**.
- The higher the factor, the higher the number of zeros in the DCT > Better Huffman coding.
- Problem: High quantization factors produce **compression artifacts**.

Small compression

Medium compression

High compression

Topic: Video compression

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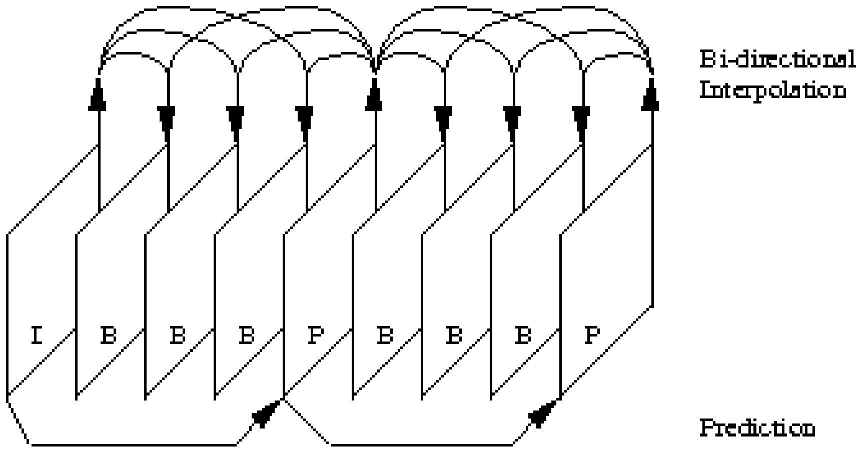
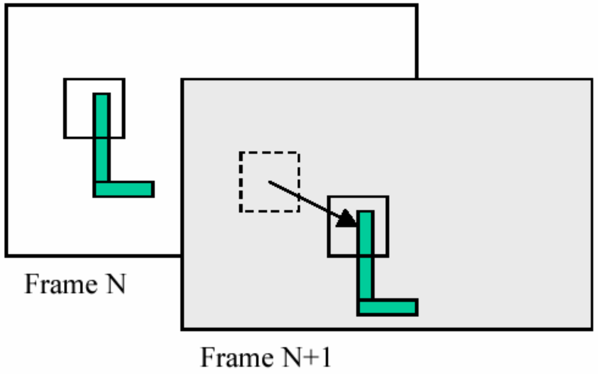
Exploiting temporal redundancy

- Using all other redundancies for JPEG:
  - Compression factor - 10:1
- Exploiting temporal redundancy for MPEG-2:
  - Compression factor – 100:1
- Temporal redundacy is of **vital importance** to video compression!

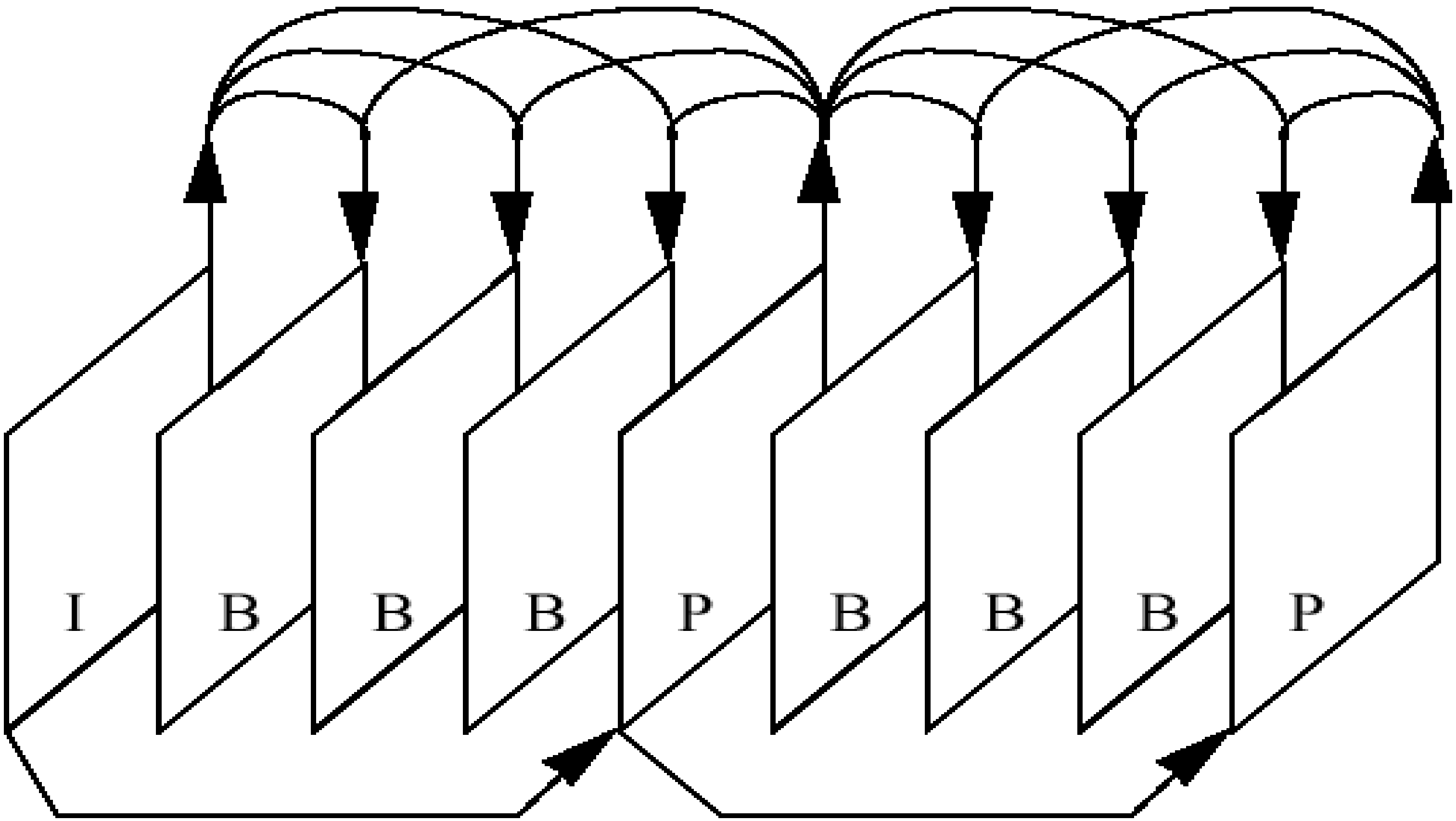
Video Compression

- H.261, H.263, DivX, MPEG–1,…
- MPEG-2
  - Images compressed as JPEG.
  - Image prediction.
  - Motion estimation.
  - DVD, Digital TV, …



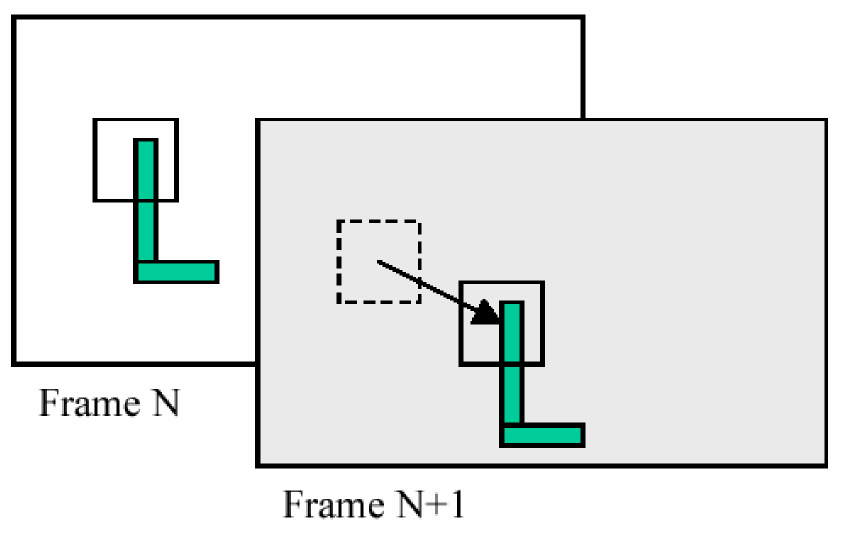


Intra-frame and Inter-frame prediciton

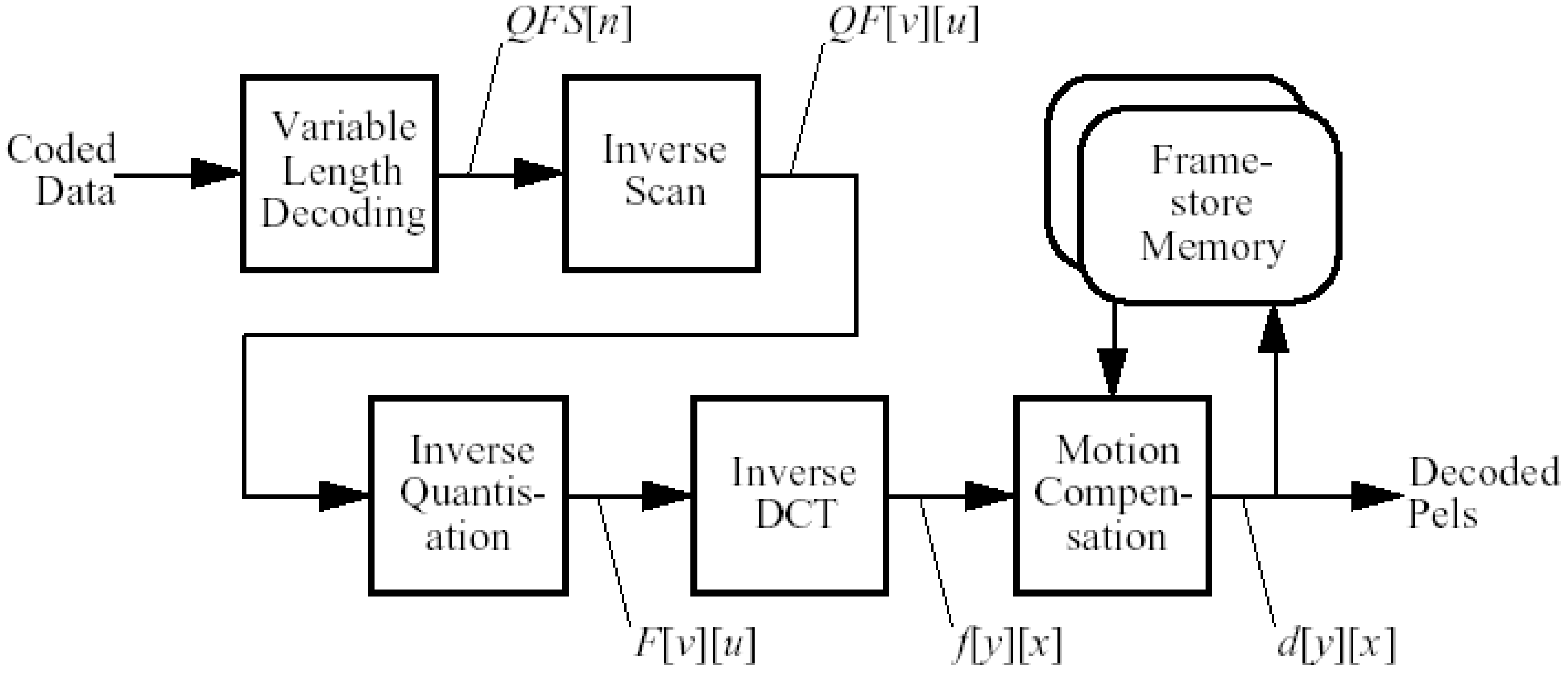


MPEG Motion estimation

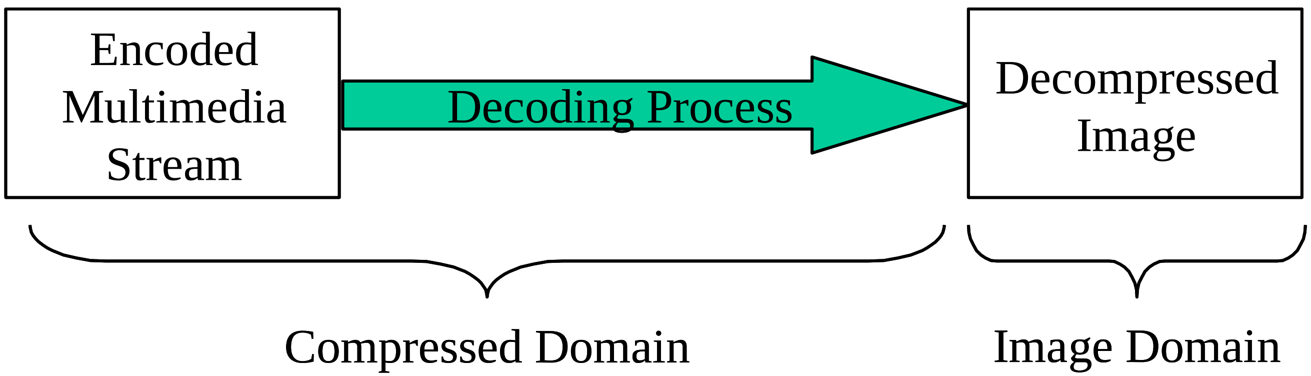
- Motion vectors:
  - B Images
  - P Images
- Point to areas in:
  - I Images
  - P Images
- Groups Of Pictures:
  - Consider error propagation.
  - Consider compression levels.



Decoder Model



Compressed Domain Processing



Can't we exploit this information?
DC Images
Motion Flow
...

Decoding Function	Decoding cost (%)
Bit stream header parsing	0.44
Huffman decoding and inverse quantization	19.00
Inverse 8x8 DCT	22.10
Motion compensation	38.64
Colour transformation and display	19.82

Resources

- Gonzalez & Woods – Chapter 6
- MPEG Compression - http://mia.ece.uic.edu/~papers/WWW/MultimediaStandards/chapter7.pdf
- Image Coding Fundamentals – http://videocodecs.blogspot.com/2007/05/image-coding-fundamentals_08.html