Digital Image Process

UINT-5

Image Data Compression

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Image Data Compression

- Large amounts of data are used to represent an image.
- Technology permits ever-increasing image resolution (spatially and in gray levels), increasing numbers of spectral bands, and there is a consequent need to limit the resulting data volume.

- Example from the remote sensing domain - Landsat D satellite broadcasts 85 x 10^6 bits of data every second and a typical image from one pass consists of 6100 x 6100 pixels in 7 spectral bands - 260 megabytes of image data.
- Japanese Advanced Earth Observing Satellite (ADEOS) has spatial resolution of 8 meters for the polychromatic band and 16 meters for the multispectral bands has the transmitted data rate of 120 Mbps.

- The amount of storage media needed is enormous.
- One possible approach to decreasing the necessary amount of storage is to work with compressed image data.

- Segmentation techniques have the side effect of image compression.
- However, image reconstruction to the original, uncompressed image is not possible.

- If compression is the main goal of the algorithm, an image is represented using a lower number of bits per pixel, without losing the ability to reconstruct the image.
- It is necessary to find statistical properties of the image to design an appropriate compression transformation of the image; the more correlated the image data are, the more data items can be removed.

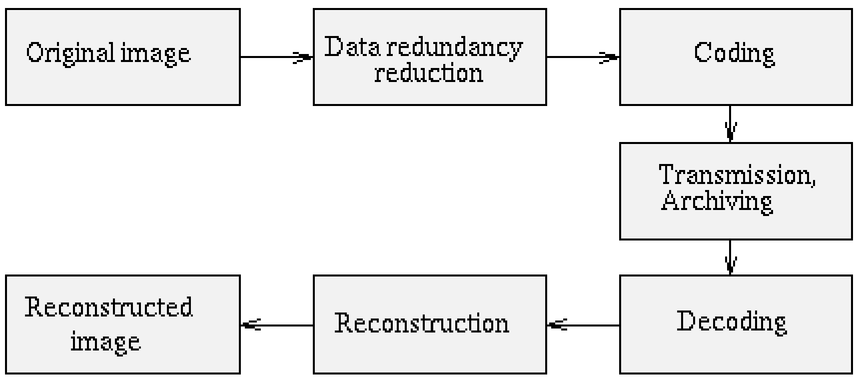

Figure 12.1 *Data compression and image reconstruction.*

- Data compression methods can be divided into two principal groups:
- **Information preserving** compression permit error-free data reconstruction (**lossless compression**).
- Compression **methods with loss of information** do not preserve the information completely (**lossy compression**).

- In image processing, a faithful reconstruction is often not necessary in practice and then the requirements are weaker, but the image data compression must not cause significant changes in an image.

- Data compression success is usually measured in the reconstructed image by the mean squared error (MSE), signal to noise ratio etc. although these global error measures do not always reflect subjective image quality.

- Image data compression design - 2 parts.
- 1) Image data properties determination
  - gray level histogram
  - image entropy
  - various correlation functions
  - etc.
- 2) Appropriate compression technique design.

- Data compression methods with loss of information are typical in image processing.

Image data properties

- **Entropy** - measure of image information content
- If an image has G gray levels, and the probability of gray level k is P(k), then entropy H_e, not considering correlation of gray levels, is defined as

$$H_e = -\sum_{k=0}^{G-1} P(k) \log_2(P(k)) \qquad (12.1)$$

- Information **redundancy** r is defined as

$$r = b - H_e \qquad (12.2)$$

- where b is the smallest number of bits with which the image quantization levels can be represented.

- A good estimate of entropy is usually not available.

- Image data entropy can however be estimated from a gray level histogram.
- Let h(k) be the frequency of gray level k in an image f, 0 <= k <= 2^b -1, and let the image size be M x N.

- The probability of occurrence of gray level k can be estimated as

$$\tilde{P}(k) = \frac{h(k)}{MN} \qquad (12.3)$$

- and the entropy can be estimated as

$$\tilde{H}_e = -\sum_{k=0}^{2^b-1} \tilde{P}(k) \log_2(\tilde{P}(k)) \qquad (12.4)$$

- The information redundancy estimate is r = b- H_e. The definition of the **compression ratio** K is then

$$K = \frac{b}{\tilde{H}_e} \qquad (12.5)$$

- These formulae give theoretical limits of possible image compression.

- Example
  - the entropy of satellite remote sensing data may be between 4 and 5, considering 8 bits per pixel
  - the information redundancy is between 3 and 4 bits
  - these data can be represented by an average data volume of 4 to 5 bits per pixel with no loss of information, and the compression ratio would be between 1.6 and 2.

Discrete image transforms in image data compression

- Basic idea: image data representation by coefficients of discrete image transforms

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- The transform coefficients are ordered according to their importance
- the least important (low contribution) coefficients are omitted.

- To remove correlated image data, the **Karhunen-Loeve transform** is the most important.
- This transform builds a set of non-correlated variables with decreasing variance.

- The variance of a variable is a measure of its information content; therefore, a compression strategy is based on considering only transform variables with high variance, thus representing an image by only the first k coefficients of the transform.

- The Karhunen-Loeve transform is computationally expensive.

- Other discrete image transforms discussed in the previous chapter are computationally less demanding.

- Cosine, Fourier, Hadamard, Walsh, or binary transforms are all suitable for image data compression.

- If an image is compressed using discrete transforms, it is usually divided into subimages of 8 x 8 or 16 x 16 pixels to speed up calculations, and then each subimage is transformed and processed separately.

- The same is true for image reconstruction, with each subimage being reconstructed and placed into the appropriate image position.

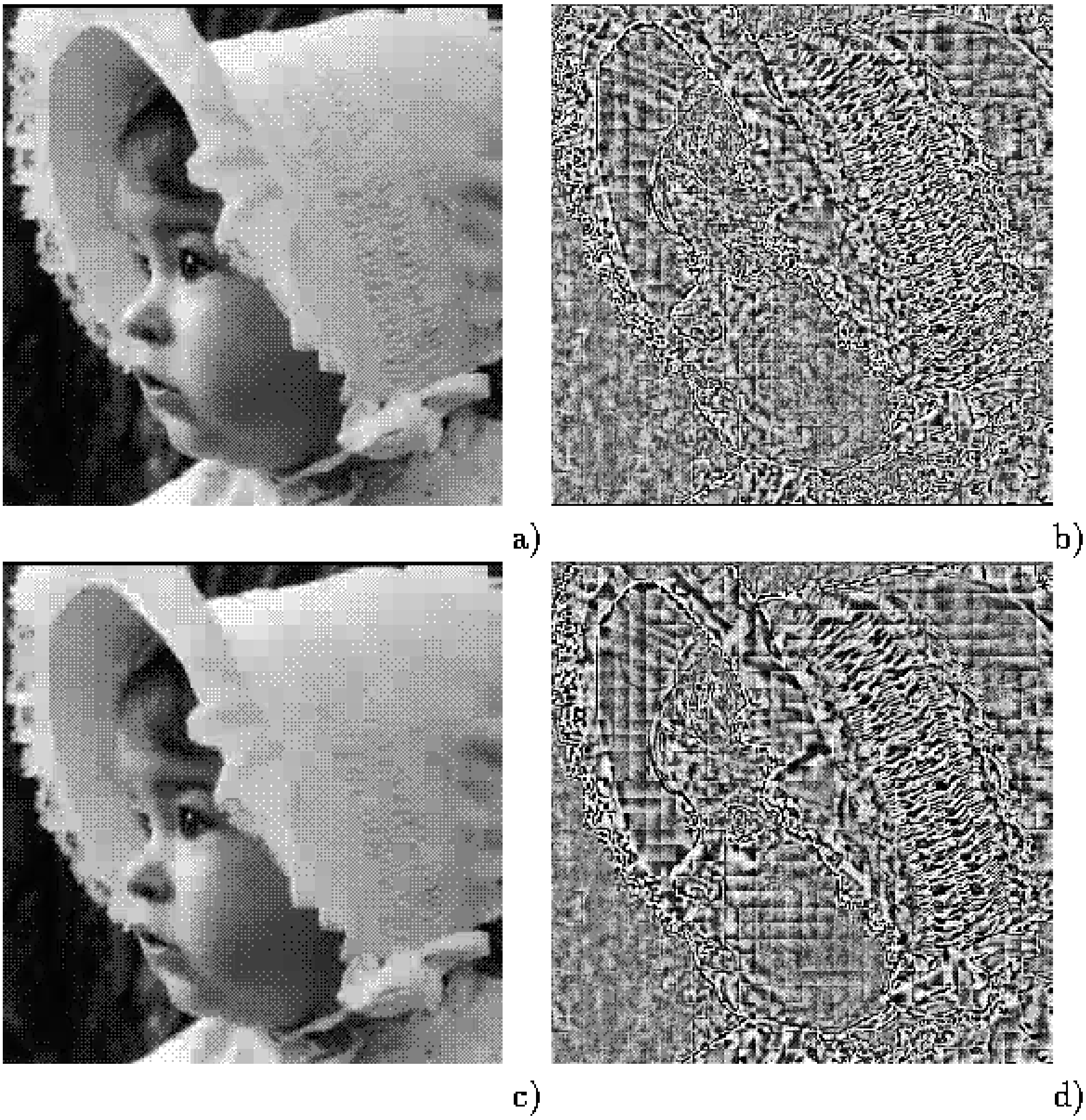


Figure 12.2 *Discrete cosine image compression: (a) Reconstructed image, compression ratio $K = 4.2$, (b) difference image – differences between pixel values in the original and the reconstructed image ($K = 4.2$); the maximum difference is 78 grey levels, mean squared reconstruction error MSE = XXX; (image is histogram equalized for visualization purposes), (c) reconstructed image, compression ratio $K = 5.6$, (d) difference image – differences between pixel values in the original and the reconstructed image ($K = 5.6$); the maximum difference is 125 grey levels, MSE = XXX; (image is histogram equalized for visualization purposes). Courtesy A. Kruger, The University of Iowa.*

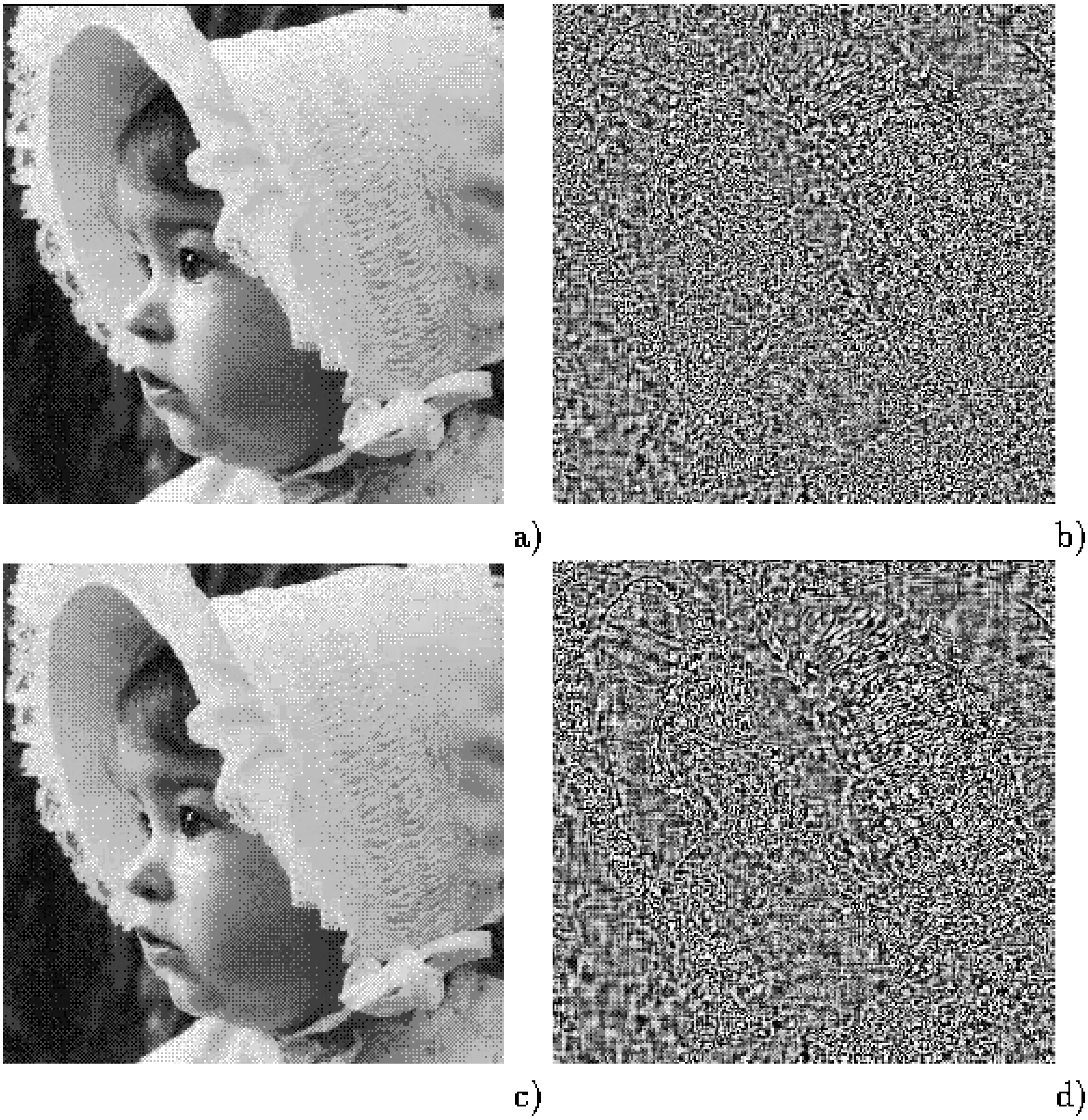


Figure 12.3 *Wavelet image compression: (a) Reconstructed image, compression ratio $K = 4.2$, (b) difference image – differences between pixel values in the original and the reconstructed image ($K = 4.2$); the maximum difference is 21 grey levels, mean squared reconstruction error $MSE = 13.9$ gray levels; (image is histogram equalized for visualization purposes), (c) reconstructed image, compression ratio $K = 5.6$, (d) difference image – differences between pixel values in the original and the reconstructed image ($K = 5.6$); the maximum difference is 31 grey levels, $MSE = 24.7$ gray levels; (image is histogram equalized for visualization purposes). Courtesy G. Prause, The University of Iowa.*

Predictive compression methods

- Predictive compressions use image information redundancy (correlation of data) to construct an estimate ~f(i,j) of the gray level value of an image element (i,j) from values of gray levels in the neighborhood of (i,j).

- In image parts where data are not correlated, the estimate ~f will not match the original value.

- The differences between estimates and reality, which may be expected to be relatively small in absolute terms, are coded and transmitted together with prediction model parameters -- the whole set now represents compressed image data.

- The gray value at the location (i,j) is reconstructed from a computed estimate ~f(i,j) and the stored difference d(i,j)

$$d(i,j) = \tilde{f}(i,j) - f(i,j) \qquad (12.6)$$

- Differential Pulse Code Modulation (DPCM)

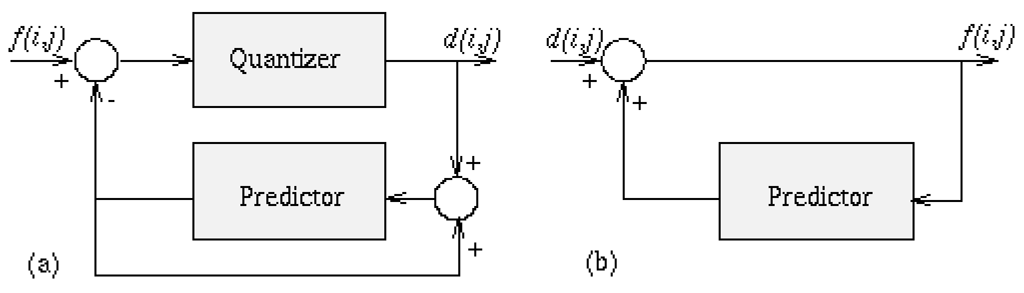


Figure 12.4 *Differential pulse code modulation: (a) Compression, (b) reconstruction.*

- Linear predictor of the third order is sufficient for estimation in a wide variety of images.

- The estimate ~f can be computed as

$$\tilde{f}(i,j) = a_1 f(i,j-1) + a_2 f(i-1,j-1) + a_3 f(i-1,j) \qquad (12.7)$$

- where a_1,a_2,a_3 are image prediction model parameters.

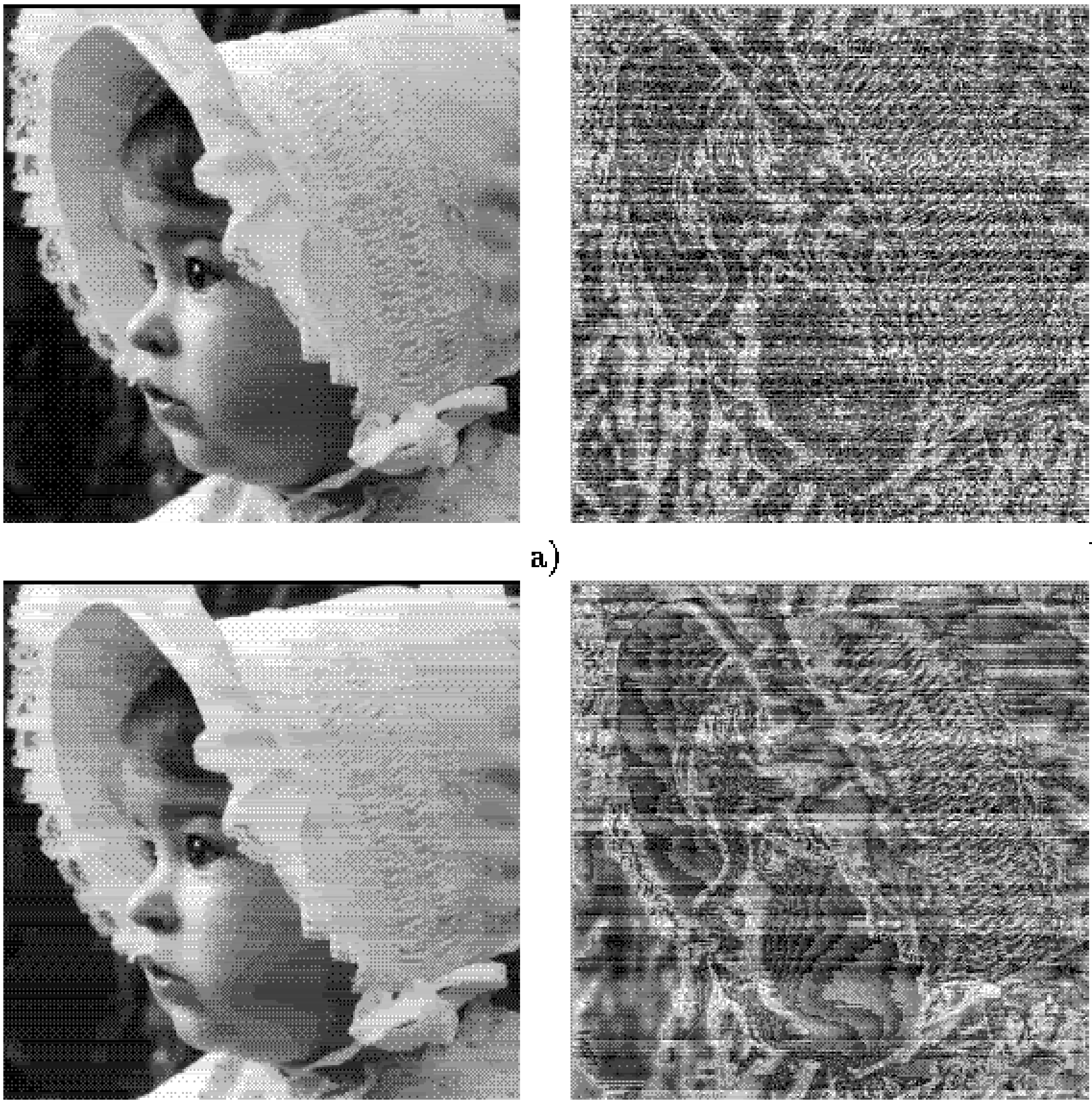
- These parameters are set to minimize the mean quadratic estimation error e,

$$e = \mathcal{E}([\tilde{f}(i,j) - f(i,j)]^2) \qquad (12.8)$$

- and the solution, assuming f is a stationary random process with a zero mean, using a predictor of the third order, is

$$\begin{aligned} a_1 R(0,0) + a_2 R(1,0) + a_3 R(1,1) &= R(0,1) \\ a_1 R(1,0) + a_2 R(0,0) + a_3 R(0,1) &= R(1,1) \\ a_1 R(1,1) + a_2 R(0,1) + a_3 R(0,0) &= R(1,0) \end{aligned} \qquad (12.9)$$

- where R(m,n) is the autocorrelation function of the random process f.



a) b)

c) d)

Figure 12.5 *Predictive compression: (a) Reconstructed image, compression ratio $K = 3.8$, (b) difference image – differences between pixel values in the original and the reconstructed image ($K = 3.8$); the maximum difference is 6 grey levels, mean squared reconstruction error MSE = XXX; (image is histogram equalized for visualization purposes), (c) reconstructed image, compression ratio $K = 6.2$, (d) difference image – differences between pixel values in the original and the reconstructed image ($K = 6.2$); the maximum difference is 140 grey levels, MSE = XXX; (image is histogram equalized for visualization purposes). Courtesy A. Kruger, The University of Iowa.*

Vector quantization

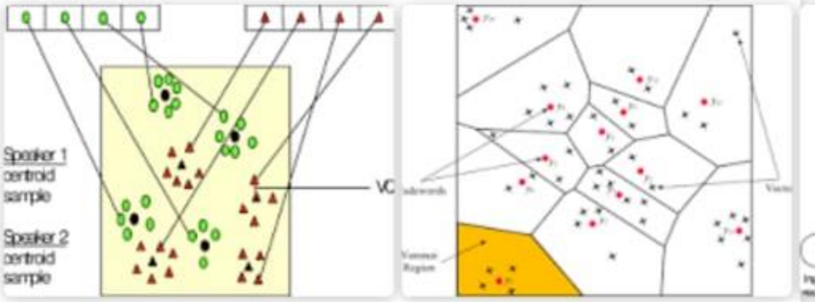
- The I/P symbol are Clubbed together in groups (vectors) & process to give the output. TheLearning vector quantization algorithm (or LVQ for short) is artificial neural network algorithm

Vector quantization (VQ) is a classical quantization technique from signal processing that allows the modeling of **probability** density functions by the distribution of prototype vectors. It was originally used for data compression.

Performance and Complexity of Vector Quentization

VQ is often loosely described as the optimal way to quantize a vector. Specifically, consider any encoding system that operates in any way on the components of the input vector and generates a binary word (or a set of binary words) with a total of up to *N* possible distinct values, and an associated decoding system that reproduces an approximation to this vector from the binary data. Such an encoding method can never provide superior performance (and generally will give inferior performance) to a suitably designed VQ coding scheme with a codebook of size *N* [1]. The proof is simply to note that the given decoder can be used to generate a unique VQ codebook whose associated VQ decoder exactly replicates the given decoder operation. Then, by replacing the given encoder with a nearest neighbor encoder based on this codebook, the VQ will necessarily match or exceed the performance of the original coding scheme.

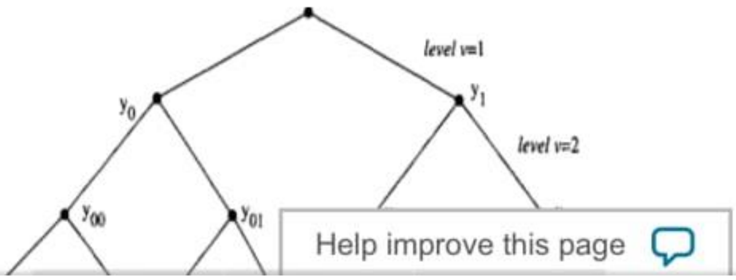
Vector quantization



Vector quantization (VQ) is a classical **quantization** technique from signal processing that allows the modeling of probability density functions by the distribution of prototype **vectors**. It was originally used for data compression.

Tree-Structured VectorQuantization:

TSVQ consists of a hierarchic arrangement of code vectors, that allows the codebook to be searched efficiently. It has the property that search time grows linearly with rate instead of exponentially. Binary trees are often used for TSVQ because they are among the most efficient in terms of complexity. The concept of TSVQ can be illustrated by examining the binary tree shown in Fig. 9. As shown, the TSVQ has a root node at the top of the tree with many paths leading from it to the bottom. The codevectors of the tree,



Hierarchical and progressive compression techniques

- A substantial reduction in bit volume can be obtained by merely representing a source as a pyramid.
- Approaches exist for which the entire pyramid requires data volume equal to that of the full resolution image..

- Even more significant reduction can be achieved for images with large areas of the same gray level if a quadtree coding scheme is applied.

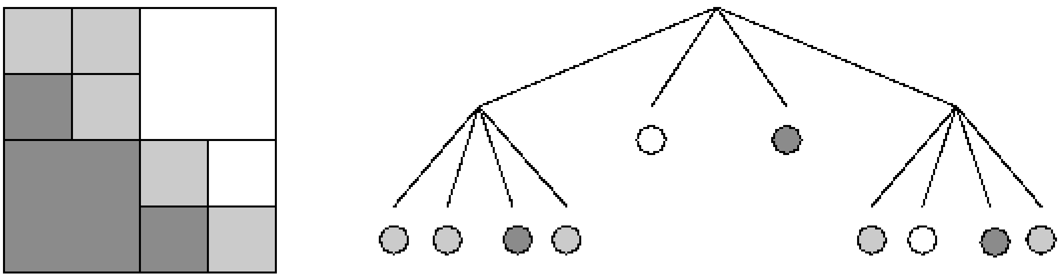


Figure 12.6 *Principle of quadtree image compression; original image and the corresponding quadtree.*

- Nevertheless, there may be an even more important aspect connected with this compression approach - the feasibility of progressive image transmission and the idea of smart compression.

- **Progressive image transmission** - transmitting all image data may not be necessary under some circumstances - e.g., searching an image database looking for a particular image.

- This approach is also commonly used to decrease the waiting time needed for the image to start appearing after transmission and is used by World Wide Web image transmissions.

- In progressive transmission, the images are represented in a pyramid structure, the higher pyramid levels (lower resolution) being transmitted first.

- The concept of **smart compression** is based on the sensing properties of human visual sensors.
- The spatial res
- on of the human eye decreases significantly with increasing distance from the optical axis.
- Therefore, the human eye can only see in high resolution in a very small area close to the point where the eye is focused.
- Similarly as with image displays, where it does not make sense to display or even transmit an image in higher resolution than that of the display device, it is not necessary to display an image in full resolution in image areas where the user's eyes are not focused.
- The main difficulty remains in determining the areas of interest in the image on which the user will focus.

- When considering a **smart progressive image transmission**, the image should be transmitted in higher resolution in areas of interest first - this improves a subjective rating of transmission speed as sensed by a human user.

- The areas of interest may be obtained in a feedback control manner from tracking the user's eyes (assuming the communication channel is fast enough).

- This smart image transmission and compression may be extremely useful if applied to dynamic image generators in driving or flight simulators, or to high definition television.

Comparison of compression methods

- Transform-based methods better preserve subjective image quality, and are less sensitive to statistical image property changes both inside a single image and between images.

- Prediction methods, on the other hand, can achieve larger compression ratios in a much less expensive way, tend to be much faster than transform-based or vector quantization compression schemes, and can easily be realized in hardware.

- If compressed images are transmitted, an important property is insensitivity to transmission channel noise. Transform-based techniques are significantly less sensitive to the channel noise - if a transform coefficient is corrupted during transmission, the resulting image distortion is homogeneously spread through the image or image part and is not too disturbing.

- Erroneous transmission of a difference value in prediction compressions causes not only an error in a particular pixel, it influences values in the neighborhood because the predictor involved has a considerable visual effect in a reconstructed image.

- Pyramid based techniques have a natural compression ability and show a potential for further improvement of compression ratios. They are suitable for dynamic image compression and for progressive and smart transmission approaches.

Coding

- Well known algorithms designed with serial data in mind are widely used in the compression of ordinary computer files to reduce disk consumption.

- Very well known is **Huffman encoding** which can provide optimal compression and error-free decompression.

- The main idea of Huffman coding is to represent data by codes of variable length, with more frequent data being represented by shorter codes.

- Many modifications of the original algorithm exist, with recent adaptive Huffman coding algorithms requiring only one pass over the data.
- More recently, the **Lempel-Ziv (or Lempel-Ziv-Welch, LZW) algorithm** of **dictionary-based coding** has found wide favor as a standard compression algorithm.
- In this approach, data are represented by pointers referring to a dictionary of symbols.

- These, and a number of similar techniques, are in widespread use for de-facto standard image representations which are popular for Internet and World Wide Web image exchange.
    - **GIF** format (Graphics Interchange Format) is probably the most popular currently in use.
        - GIF is a creation of Compuserve Inc., and is designed for the encoding of RGB images (and the appropriate palette with pixel depths between 1 and 8 bits.
        - Blocks of data are encoded using the LZW algorithm.
        - GIF has two versions - 87a and 89a, the latter supporting the storing of text and graphics in the same file.
    - **TIFF** (Tagged Image File Format) was first defined by the Aldus Corporation in 1986, and has gone through a number of versions to incorporate RGB color, compressed color (LZW), other color formats and ultimately (in Version 6), JPEG compression (below) -- these versions all have backward compatibility.

JPEG image compression

- There is an increasing effort to achieve standardization in image compression.
- The Joint Photographic Experts Group (**JPEG**) has developed an international standard for general purpose, color, still-image compression.

- **MPEG** standard (Motion Picture Experts Group) was developed for full-motion video image sequences with applications to digital video distribution and high definition television (HDTV) in mind.

JPEG - still image compression

- JPEG is widely used in many application areas.

- Four compression modes are furnished
    1. Sequential DCT-based compression
    2. Progressive DCT-based compression
    3. Sequential lossless predictive compression
    4. Hierarchical lossy or lossless compression

- While the lossy compression modes were designed to achieve compression ratios around 15 with very good or excellent image quality, the quality deteriorates for higher compression ratios.

- A compression ratio between 2 and 3 is typically achieved in the lossless mode.

- **Sequential JPEG Compression** consists of a forward DCT transform, a quantizer, and entropy encoder while decompression starts with entropy decoding followed by dequantizing and inverse DCT.

- In the compression stage, the unsigned image values from the interval [0,(2^b)-1] are first shifted to cover the interval [-2^(b-1),2^(b-1)-1].

- The image is then divided into 8x8 blocks and each block is independently transformed into the frequency domain using the DCT-II transform.

- Many of the 64 DCT coefficients have zero or near-zero values in typical 8x8 blocks which forms the basis for compression.

- The 64 coefficients are quantized using a quantization table Q(u,v) of integers from 0 to 255 that is specified by the application to reduce the storage/transmission requirements of coefficients that contribute little or nothing to the image content.
- The following formula is used for quantization

$$F_Q(u,v) = round\left[\frac{F(u,v)}{Q(u,v}\right] \qquad (12.10)$$

- After quantization, the dc-coefficient F(0,0) is followed by the 63 ac-coefficients that are ordered in a 2D matrix in a zig-zag fashion according to their increasing frequency.

- The dc-coefficients are then encoded using predictive coding, the rationale being that average gray levels of adjacent 8x8 blocks (dc-coefficients) tend to be similar.

- The last step of the sequential JPEG compression algorithm is entropy encoding.
  - Two approaches are specified by the JPEG standard.
  - The baseline system uses simple Huffman coding while the extended system uses arithmetic coding and is suitable for a wider range of applications.

- Sequential JPEG decompression uses all the steps described above in the reverse order. After entropy decoding (Huffman or arithmetic), the symbols are converted into DCT coefficients and dequantized

$$F'_Q(u,v) = F_Q(u,v)Q(u,v) \qquad (12.11)$$

- where again, the Q(u,v) are quantization coefficients from the quantization table that is transmitted together with the image data.

- Finally, the inverse DCT transform is performed and the image gray values are shifted back to the interval [0,(2^b)-1].

- In **Progressive JPEG Compression**, a sequence of scans is produced, each scan containing a coded subset of DCT coefficients.
- A buffer is needed at the output of the quantizer to store all DCT coefficients of the entire image.
- These coefficients are selectively encoded.

- Three algorithms are defined as part of the JPEG progressive compression standard;
  - **progressive spectral selection**
  - **progressive successive approximation**
  - **combined progressive algorithm**.

- In the progressive spectral selection approach, the dc-coefficients are transmitted first, followed by groups of low frequency and higher frequency coefficients.

- In the progressive successive approximation, all DCT coefficients are sent first with lower precision and their precision increases as additional scans are transmitted.

- The combined progressive algorithm uses both of the above principles together.

- **Sequential Lossless JPEG Compression**

- The lossless mode of the JPEG compression uses a simple predictive compression algorithm and Huffman coding to encode the prediction differences.

- **Hierarchical JPEG Compression**
- Using the hierarchical JPEG mode, decoded images can be displayed either progressively or at different resolutions.
- A pyramid of images is created and each lower resolution image is used as a prediction for the next higher resolution pyramid level.
- The three main JPEG modes can be used to encode the lower-resolution images - sequential DCT, progressive DCT, or lossless.

- In addition to still image JPEG compression, motion JPEG (**MJPEG**) compression exists that can be applied to real-time full-motion applications.
- However, MPEG compression represents a more common standard and is described below.
