Digital Image Formats

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- Color representation
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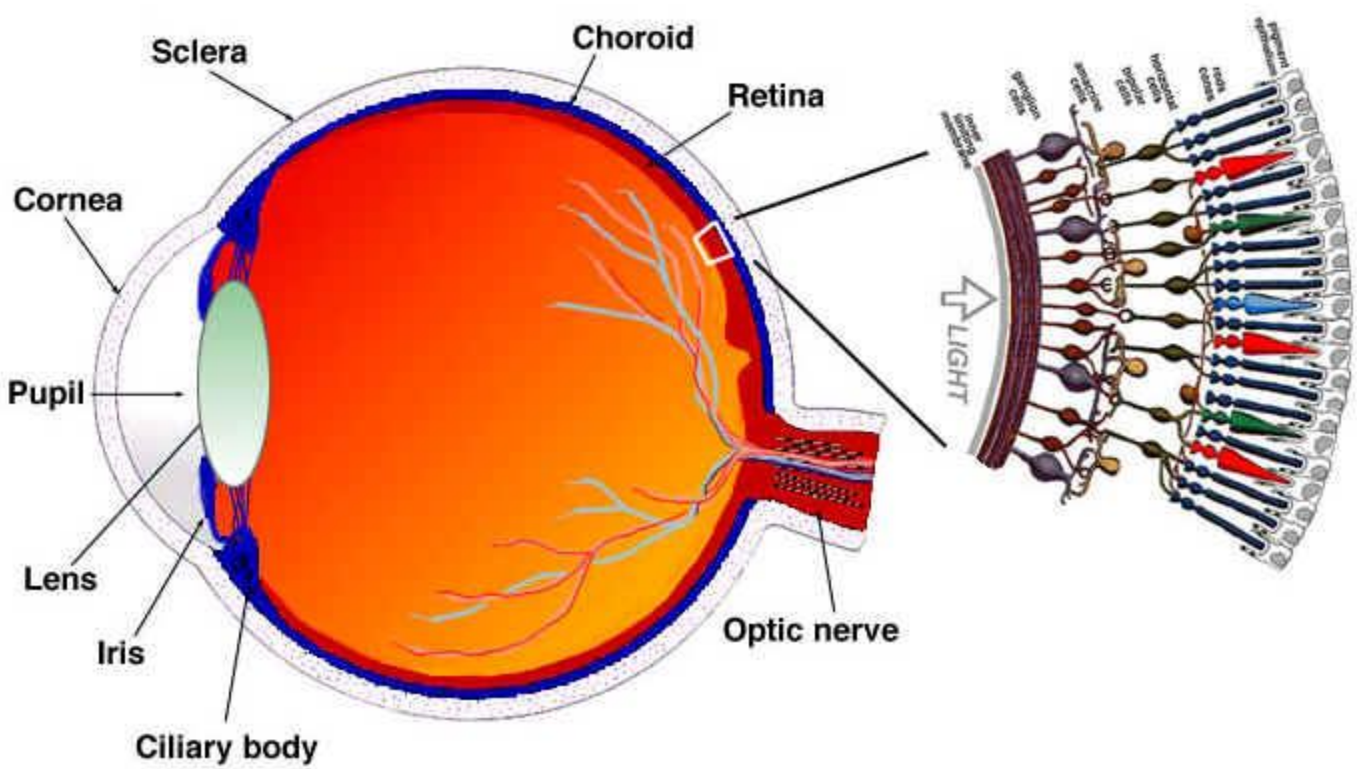
1. Color Representation

- Visible light is a superposition of electromagnetic waves with wavelengths spanning the interval between approximately 380 nm and 750 nm.
- Each color can be associated with the spectral density function P (λ), which describes the amount of energy present at wavelength λ.

1. Color Representation



1. Color Representation

- Denoting the amount of each color as R, G, and B, where each number is from the interval [0, 1] (zero intensity to full intensity), each color can be represented as a three-dimensional vector in the RGB color cube $(R, G, B) \in [0, 1]^3$.
- Hardware systems that emit light are usually modeled as additive.

1. Color Representation

- The subtractive color model is used for hardware devices that create colors by absorption of certain wavelengths rather than emission of light.

1. Color Representation

- The standard basic colors for subtractive systems are, by convention, cyan, magenta, and yellow, leading to color representation using the vector CMY. These three colors are obtained by removing from white the colors red, green, and blue, respectively.

$$C = 1 - R,$$

$$M = 1 - G,$$

$$Y = 1 - B.$$

1. Color Representation

- A very popular color system is the YUV model originally developed for transmission of color TV signals.
- The requirement of backward compatibility with old black-andwhite TVs led the designers to form the color TV signal as luminance augmented with chrominance signals.

1. Color Representation

- The luminance Y is defined as a weighted linear combination of the RGB channels with weights determined by the sensitivity of the human eye to the three RGB colors:

$$Y = 0.299R + 0.587G + 0.114B$$

1. Color Representation

- The chrominance components are the differences conveying the color information:

$$U = R - Y,$$

$$V = B - Y$$

1. Color Representation

$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.701 & -0.587 & -0.114 \\ -0.299 & -0.587 & 0.886 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1 & 1 & 0 \\ 1 & -0.509 & -0.194 \\ 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} Y \\ U \\ V \end{pmatrix}$$

1. Color Representation

$$\begin{pmatrix} Y \\ C_r \\ C_b \end{pmatrix} = \begin{pmatrix} 0 \\ 128 \\ 128 \end{pmatrix} + \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.5 & -0.419 & -0.081 \\ -0.169 & -0.331 & 0.5 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

1. Color Representation

- Because human eyes are much less sensitive to changes in chrominance than in luminance, the chrominance signals are often represented with fewer bits without introducing visible distortion into the image.

1. Color Representation

- Even though some image formats allow arbitrarily accurate representation of the color intensity values, most formats represent the intensities in a quantized form using a fixed number.
- The most appropriate color sampling is heavily dependent on the application.

1. Color Representation

n_C	Colors	Application
1	2	Fax, black-and-white drawings
4	16	Line drawings, charts, cartoons
8	256	Grayscale images, true-color natural images
12	4096	Grayscale medical images, digital sensor output, scans
14	16384	Digital sensor output, scans, film-quality digital images
16	65536	Photo-realistic synthetic images, scans, satellite imagery

2. Spatial-domain formats

- The most intuitive way to represent natural images in a computer is to sample the colors on a sufficiently dense rectangular grid.

2. Spatial-domain formats

- In a raster format, the image data is typically stored in a row-by-row manner with one or more bytes (or bits) per pixel depending on the format and the number of bits allocated per pixel.

2. Spatial-domain formats

- Palette formats are typically used for images with low color depth, such as computer-generated graphics, line drawings, and cartoons.
- The image data is a rectangular $M \times N$ array of 8-bit pointers to the palette.

3. Transform-domain formats

- Tests on human subjects showed that our visual system is fairly insensitive to small changes in color or highspatial-frequency noise.

3. Transform-domain formats

- Engineers working in data compression have long realized this fact and proposed several much more efficient image formats that work by transforming the image into a different domain where it can be represented in an easily compressible “sparse” form.

3. Transform-domain formats

- The two most commonly used transforms today are the Discrete Cosine Transform (DCT) and the Discrete Wavelet Transform (DWT). The DCT is at the heart of the JPEG format, while the DWT is used in JPEG2000.

3. Transform-domain formats

- JPEG stands for the Joint Photographic Experts Group that finalized the standard in 1992. In this section, we review basic properties of the format relevant to steganography.

3. Transform-domain formats

Compression:

1. Color transformation
2. Division into blocks and subsampling
3. DCT transform
4. Quantization
5. Encoding and lossless compression

3. Transform-domain formats

1. Color subsampling and padding

- The image is divided into macroblocks of 16 × 16 pixels.
- Each macroblock produces four 8 × 8 luminance blocks and 1, 2, or 4 blocks for each chrominance.

3. Transform-domain formats

1. Color subsampling and padding

- If the image dimensions, $M \times N$, are not multiples of 8, the image is padded to the nearest larger multiples.
- Also, before applying the DCT, all pixel values are shifted by subtracting 128 from them.

3. Transform-domain formats

2. Discrete cosine transform

- For an 8 × 8 block of luminance (or chrominance) values B[i, j], i, j = 0, . . . , 7, the 8 × 8 block of DCT coefficients d[k, l], k, l = 0, . . . , 7 is computed as a linear combination of luminance values:

$$d[k,l] = \sum_{i,j=0}^{7} f[i,j;k,l]B[i,j]$$

3. Transform-domain formats

2. Discrete cosine transform

$$f[i,j;k,l] = \sum_{i,j=0}^{7} \frac{w[k]w[l]}{4} \cos\frac{\pi}{16}k(2i+1) \cos\frac{\pi}{16}l(2j+1)$$

$$w[0] = \frac{1}{\sqrt{2}}$$

$$w[k>1] = 1$$

3. Transform-domain formats

3. Quantization

- The purpose of quantization is to enable representation of DCT coefficients using fewer bits, which necessarily results in loss of information.

$$D[k,l] = round\left(\frac{d[k,l]}{Q[k,l]}\right); k,l \in \{0, \dots 7\}$$

3. Transform-domain formats

3. Quantization

- The JPEG standard recommends a set of quantization matrices indexed by a quality factor qf ∈ {1, 2, . . . , 100}.

$$Q_{q_f} = \begin{cases} \max\left\{1, round\left(2Q_{50}\left(1 - \frac{q_f}{100}\right)\right)\right\}, q_f > 50 \\ \min\left\{255 \cdot 1, round\left(\frac{50Q_{50}}{q_f}\right)\right\}, q_f \leq 50 \end{cases}$$

3. Transform-domain formats

3. Quantization

$$\mathbf{Q}_{50}^{(\text{lum})} = \begin{pmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{pmatrix}$$

3. Transform-domain formats

3. Quantization

$$\mathbf{Q}_{50}^{(\mathrm{chr})} = \begin{pmatrix} 17 & 18 & 24 & 47 & 99 & 99 & 99 & 99 \\ 18 & 21 & 26 & 66 & 99 & 99 & 99 & 99 \\ 24 & 26 & 56 & 99 & 99 & 99 & 99 & 99 \\ 47 & 66 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \end{pmatrix}.$$

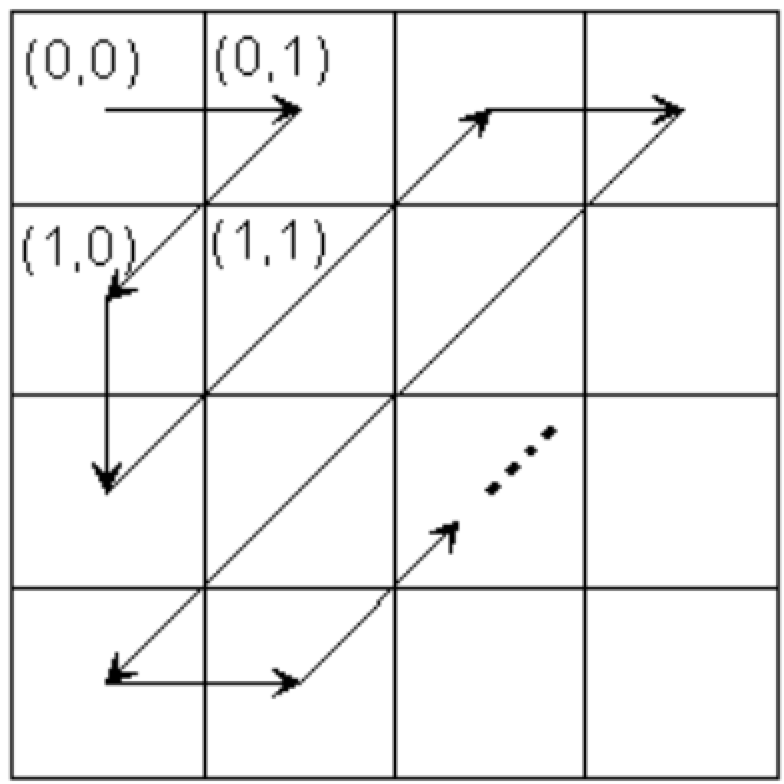
3. Transform-domain formats

4. Coding

- The quantized matrix D is now ready for the final step of compression. Before storage, all coefficients of D are converted by an encoder to a stream of binary data.
- After quantization, it is quite common for most of the coeffecients to equal zero. JPEG takes advantage of this by encoding quantized coefficients in the zig-zag sequence.

3. Transform-domain formats

4. Coding



3. Transform-domain formats

4. Decompression

- The decompression works in the opposite order. After reading the quantized DCT blocks from the JPEG file, each block of quantized DCT coefficients D is multiplied by the quantization matrix.