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Digital Image Processing

Introduction to Image Compression

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Image Compression

- New techniques have led to the development of robust methods to reduce the **size** of the image, video, audio or other types of data.
- Such methods are extremely vital in many applications that manipulate and store massive amounts of data. **Without compression, most of these applications would not be feasible.**
- Informally, we refer to the process of **data size reduction** as a **compression process**. We will define this process in a more formal way later.
- In the cases where the signal is defined as an image, a video stream, or an audio signal, the generic problem of compression is to minimise the bit rate of their digital representation using binary bits.
- On the architecture front, it is now feasible to put sophisticated compression processes on relatively low-cost hardware; this has spurred a great deal of activity in developing multimedia systems for the large consumer market.

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Why are signals amenable to compression?

- **There is considerable redundancy in the signal.**

1. Within a single image or a single video frame, there exists significant correlation among neighbour samples. This correlation is referred to as **spatial correlation**.
2. For data acquired from multiple sensors (such as satellite images), there exists significant correlation amongst samples from these sensors in the frequency domain. This correlation is referred to as **spectral correlation**.
3. For temporal data (such as video), there is significant correlation amongst samples in different segments of time. This is referred to as **temporal correlation**.

Why do we need compression standards ?

- Multimedia data comprising image, video, and audio has become just another data type.
- This usually implies that multimedia information will be digitally encoded so that it can be **processed**, **stored**, and **transmitted** along with other digital data types.
- For such data usage to be pervasive, it is essential that the data encoding is standard across different platforms and applications.
- This will foster widespread development of applications and will also promote interoperability among systems from different vendors.
- Furthermore, standardisation can lead to the development of cost-effective implementations, which in turn will promote the widespread use of multimedia information.
- This is the primary motivation behind the emergence of image and video compression standards.

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Examples of data compression

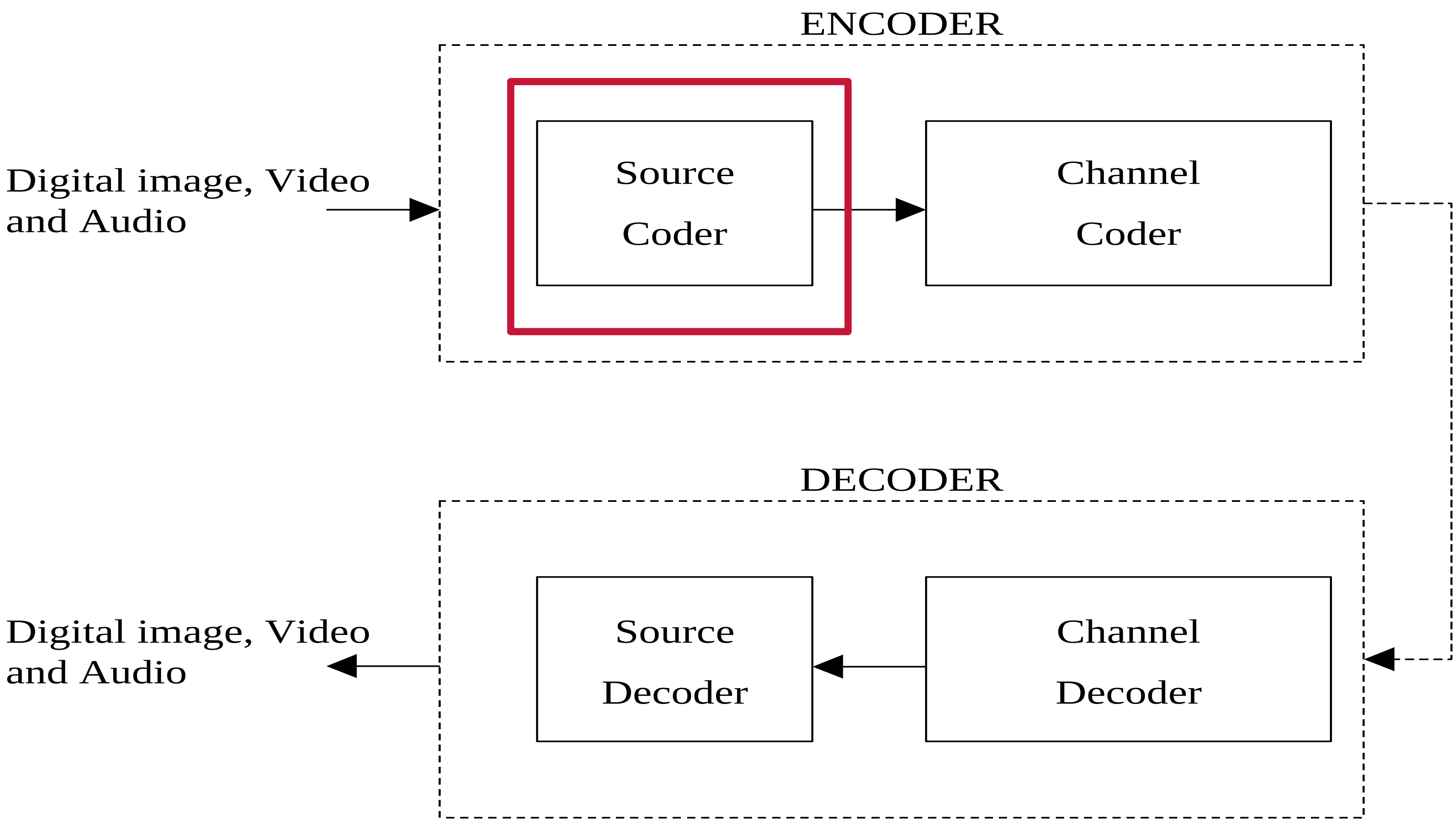
- **Example 1: Facsimile image transmission (FAX).**
  - In most facsimile machines, the document is scanned and digitised. Typically, an 8.5×11 square inches page is scanned at 200 dpi **(dots per inch - the number of individual dots that can be placed in a line within the span of 1 inch).** This is $200 \times 200 = 40000$ dots per square inch.
  - The above results in $8.5 \times 11 \times 40000 = 3.74$ Mbits. Transmitting this data over a low-cost 14.4 kbits/s modem would require 5.62 minutes.
  - With compression, the transmission time can be reduced to 17 seconds. This results in substantial savings in transmission costs.

- **Example 2: Video-based CD-ROM application**
  - Full-motion video, at 30 fps and a 720×480 resolution, generates data at 20.736 Mbytes/s.
  - At this rate, only 31 seconds of video can be stored on a 650 MByte CD-ROM.
  - Compression technology can increase the storage capacity to 74 minutes, for VHS-grade video quality.

Applications for image, video, and audio compression

Application	Data Rate	
	Uncompressed	Compressed
Voice 8 ksamples/s, 8 bits/sample	64 kbps	2-4 kbps
Slow motion video (10fps) framesize 176x120, 8bits/pixel	5.07 Mbps	8-16 kbps
Audio conference 8 ksamples/s, 8 bits/sample	64 kbps	16-64 kbps
Video conference (15fps) framesize 352x240, 8bits/pixel	30.41 Mbps	64-768 kbps
Digital audio 44.1 ksamples/s, 16 bits/sample	1.5 Mbps	1.28-1.5 Mbps
Video file transfer (15fps) framesize 352x240, 8bits/pixel	30.41 Mbps	384 kbps
Digital video on CD-ROM (30fps) framesize 352x240, 8bits/pixel	60.83 Mbps	1.5-4 Mbps
Broadcast video (30fps) framesize 720x480, 8bits/pixel	248.83 Mbps	3-8 Mbps
HDTV (59.94 fps) framesize 1280x720, 8bits/pixel	1.33 Gbps	20 Mbps

A generic compression system



Source coder – Compression ratio

- The **source coder** performs the compression process by reducing the input data rate to a level that can be supported by the storage or transmission medium.

- The output bit rate of the encoder is measured in **bits per sample** or **bits per second**.

- For image or video data, a pixel is the basic element; thus, bits per sample is also referred to as **bits per pixel**.

- In the literature, the term **compression ratio** c_r, is also used instead of **bit rate** to characterise the capability of the compression system. An intuitive definition is:

$$c_r = \frac{\textbf{source coder input size}}{\textbf{source coder output size}}$$

Compression ratio

- The definition of compression ratio is somewhat ambiguous and depends on the data type and the specific compression method that is employed.
- For a still-image, size could refer to the bits needed to represent the entire image.
- For video, size could refer to the bits needed to represent one frame of video.
- Many compression methods for video do not process each frame of video, hence, a more commonly used notion for size is the bits needed to represent one second of video.

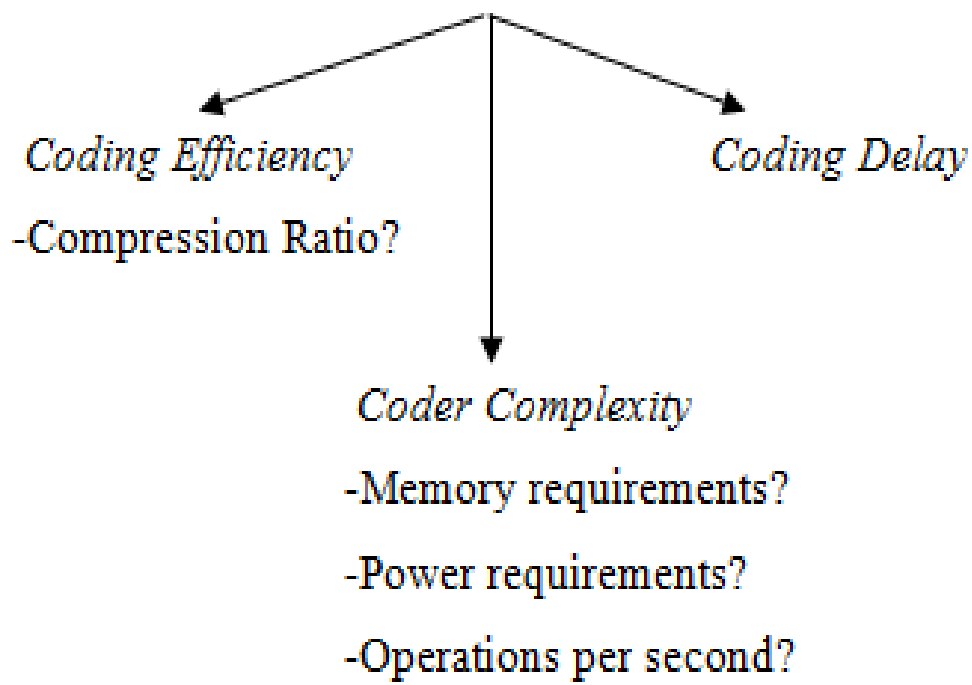
$$c_r = \frac{\textbf{source coder input size}}{\textbf{source coder output size}}$$

Compression requirements

- **Specified level of signal quality**. This constraint is usually applied at the decoder.
- **Implementation complexity**. This constraint is often applied at the decoder, and in some instances at both the encoder and the decoder.
- **Communication delay**. This constraint refers to the end to end delay, and is measured from the start of encoding a sample to the complete decoding of that sample.
- **Coding efficiency**. This constraint refers on how good (high) is the achieved compression ratio.
- Note that, these constraints have different importance in different applications. For example, in a two-way teleconferencing system, the communication delay might be the major constraint, whereas, in a television broadcasting system, signal quality and decoder complexity might be the main constraints.

Lossless compression - Trade offs

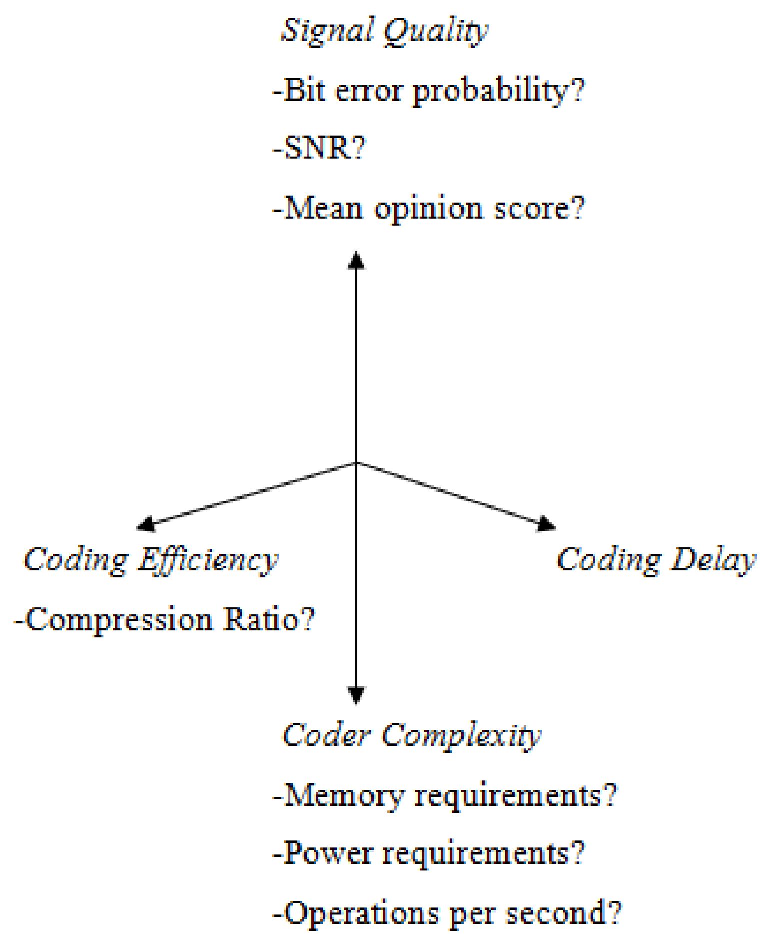
- Lossless compression refers to compression methods which require that the reconstructed data and the original data are identical in value.
- Required signal quality in not an issue here, since we do not allow any loss of information due to compression.



Lossy compression

- The majority of the applications in image or video data processing do not require that the reconstructed data and the original data are identical in value.
- Thus, some amount of loss is permitted in the reconstructed data. A compression process that results in an imperfect reconstruction is referred to as a lossy compression process.
- This compression process is irreversible. In practice, most irreversible compression processes degrade rapidly the signal quality when they are repeatedly applied on previously decompressed data.
- The choice of a specific lossy compression method involves trade-offs along the four dimensions shown in figure below.
- Due to the additional degree of freedom, namely, in the signal quality, a lossy compression process can yield higher compression ratios than a lossless compression scheme.

Lossy compression - Trade offs



Lossy compression – Signal quality – SNR

- The term **signal quality** is often used to characterise the signal at the output of the decoder. There is no universally accepted measure for signal quality.

- One measure that is often cited is the Signal-to-Noise-Ratio, which can be expressed as

$$SNR = 10log_{10}\frac{\textbf{encoder input signal energy}}{\textbf{noise signal energy}}$$

- The noise signal energy is defined as the energy measured for a hypothetical (noise) signal that is the difference between the encoder input signal and the decoder output signal.

- High SNR values do not always correspond to signals with perceptually high quality.

- We often use personal (subjective) assessment of the quality of the compressed signal.