CHAP 1

📌 Introduction to Video Processing

- **Video signal** refers to a **sequence of time-varying images (frames)** that create the illusion of motion.
- A **still image** remains constant over time, while a **video signal** consists of images that change dynamically.
- **Frame rate** determines motion smoothness. **Higher frame rates** create fluid motion, while **lower frame rates** cause choppiness.
- **Digital video processing** involves converting a continuous natural scene into a digital format for storage, transmission, and display.

📌 Analog Video Signals

- **Despite digital advancements, analog formats remain relevant in some applications.**
- **Key Analog Video Formats:**
    - **NTSC (National Television Systems Committee)** – Used in North America and Japan, operating at **60 fields per second**.
    - **PAL (Phase Alternating Line)** – Used in Europe, Australia, and parts of Asia, operating at **50 fields per second**.
    - **SECAM (Sequential Color with Memory)** – Used in France, Russia, and some African countries, also operating at **50 fields per second**.
- Analog signals rely on **interlaced scanning**, where odd and even lines of an image are **scanned separately** to reduce flickering and improve motion.

📌 Progressive vs. Interlaced Scanning

Progressive Scan

- Each frame is scanned completely **line-by-line**, producing a sharper and more detailed image.
- Used in **computer monitors, digital cinema, and HDTVs**.
- Provides **better image quality** at high resolutions but requires more bandwidth.

Interlaced Scan

- Frames are divided into two **fields (odd and even lines)**, displayed alternately.
- Used in **TV broadcasts and older CRT displays** to reduce flickering while conserving bandwidth.
- **Frame rates:**
    - **NTSC (60 fields/sec) → 30 full frames/sec**
    - **PAL & SECAM (50 fields/sec) → 25 full frames/sec**

📌 Digital Video

- **Digital video** converts an image into **pixels**, where each pixel is assigned an intensity value.
- **Advantages over Analog Video:**
    - No signal degradation over time.
    - Easier to edit, store, and transmit.
    - Compatible with **modern storage and compression techniques**.

Key Components of Digital Video

- **Spatial Sampling:**
    - Converts an image into a grid of **pixels**, where each pixel represents intensity (brightness).
    - Human Visual System (**HVS**) is **more sensitive to brightness than color**.
- **Temporal Sampling:**
    - Defines how frequently frames are captured per second.

- **Standard frame rates:**
  - **24 FPS (Movies & TV)**
  - **30 FPS (NTSC video)**
  - **60 FPS (High-motion content, gaming, sports)**

Common Digital Video Formats

Format	Resolution (Pixels)	Typical Applications
Sub-QCIF	128 × 96	Mobile multimedia
QCIF	176 × 144	Video conferencing, mobile multimedia
CIF	352 × 288	Video conferencing
4CIF	704 × 576	SDTV, DVD-Video
16CIF	1408 × 1152	HDTV, DVD-Video

📌 Video Compression

Why is Compression Necessary?

- **Uncompressed video files are extremely large**, making storage and transmission inefficient.
- **Example:** A **176×144-pixel video at 30 FPS and 24-bit color** requires **18.25 Mbps**, which is impractical for regular network transmission.

Types of Redundancy in Video

1. **Spatial Redundancy** – **Similarities within a single frame** (neighboring pixels have similar values).
2. **Temporal Redundancy** – **Similarities between successive frames** (motion changes are often small).

Compression Methods

- **Lossless Compression:**
  - Retains **all original data**, ensuring no quality loss.
  - Used in **medical imaging, archival storage, and scientific applications**.
- **Lossy Compression:**
  - Discards some **less critical data** to achieve higher compression.
  - Used in **streaming, DVD storage, and online multimedia**.

Compression Techniques

- **Intraframe Coding (Spatial Compression):**
  - Reduces spatial redundancy **within a single frame**.
  - Uses the **Discrete Cosine Transform (DCT)** to reduce pixel correlation.
- **Interframe Coding (Temporal Compression):**
  - Exploits redundancy **between successive frames**.
  - Uses **motion estimation and compensation** techniques.

📌 Video Frame Types

To achieve efficient compression, different frame types are used:

1. **I-Frame (Intra-coded Frame)**
    - **Fully self-contained**, stores complete image data.
    - **High quality but large file size.**
2. **P-Frame (Predictive-coded Frame)**
    - Stores **differences from the previous frame**, reducing size.
    - Relies on motion estimation.
3. **B-Frame (Bidirectional-coded Frame)**
    - Uses **both previous and future frames** to enhance compression.
    - **Most efficient** but computationally complex.
4. **Group of Pictures (GOP)**
    - A structured sequence of I, P, and B frames.
    - **Example:** "I B B P B B P B B I"

📌 Motion Estimation & Compensation

- **Motion Estimation:** Detects movement between frames.
- **Motion Compensation:** Uses previous frames to reconstruct new ones.

Common Motion Estimation Techniques:

- **Block Matching Algorithm:**
    - Compares **small rectangular blocks** between frames.
- **Error Metrics for Motion Estimation:**
    - **Mean Squared Error (MSE)**
    - **Mean Absolute Error (MAE)**
    - **Sum of Absolute Differences (SAD)**

📌 Subsampling & Color Space Conversion

- Human eyes are **more sensitive to brightness (luminance) than color (chrominance)**.
- Subsampling reduces **color data while maintaining brightness information**.

Common Subsampling Ratios

Format	Description
4:4:4	No subsampling, highest quality
4:2:2	Reduces color resolution by 50%
4:1:1	More compressed, lower quality

📌 Video Compression Standards

ITU-T Standards (Video Conferencing)

- **H.261 (1991):** Designed for **ISDN video conferencing**.
- **H.263 (1996):** Optimized for **low bit-rate applications**.

MPEG Standards (Multimedia & Broadcasting)

- **MPEG-1 (1993):** Used for **CD-ROM video, bit rate ~1.2 Mbps**.
- **MPEG-2 (1995):** Used for **DVDs, TV broadcasts, supports 4-80 Mbps**.

- **MPEG-4 (1998):** Designed for **internet video, mobile applications (24-1024 Kbps)**.

📌 Scalable Video Coding

- **Allows a single video file to adapt to multiple resolutions, frame rates, and bit rates.**
- **Types of Scalability:**
    - **Temporal Scalability:** Adjusts frame rate.
    - **Data Rate Scalability:** Supports variable bit rates.
    - **Spatial Scalability:** Enables different resolutions (e.g., mobile vs. HDTV).

CHAP 2

📌 Analog-to-Digital Converters (ADCs) Basics

- **ADCs** convert real-world **analog signals** into **digital signals** that microcontrollers and digital systems can process.
- **Analog signals** are continuous, while **digital signals** are discrete, represented in binary values.
- ADCs are essential in **IoT applications**, where real-time signals like **sound, light, temperature, and motion** need to be processed.

📌 Why Are ADCs Needed?

- **Microcontrollers cannot directly read analog signals.** They can only process digital signals (0s and 1s).
- ADCs **sample**, **quantify**, and **convert** analog signals into binary values for digital processing.
- The two **most important ADC characteristics** are:
    1. **Sampling Rate (or Sampling Frequency)** – Determines how frequently the signal is sampled.
    2. **Resolution** – Defines the precision of the ADC (measured in bits).

📌 ADC Sampling Rate (fs) and Aliasing

What is Sampling Rate?

- The **sampling rate** defines how many times per second the ADC measures the analog signal.
- Measured in **samples per second (SPS)** or **Hertz (Hz)**.
- Formula: fs=1Tf_s = \frac{1}{T} Where:
    - fsf_s = Sampling Rate (Hz or S/s)
    - TT = Time between consecutive samples (seconds)

Importance of a Proper Sampling Rate

- **Higher sampling rate** → More accurate digital representation.
- **Lower sampling rate** → May cause aliasing (incorrect reconstruction of the original signal).
- **Aliasing** occurs when the sampling rate is **too low** compared to the input signal's frequency.
- To **prevent aliasing**, the **Nyquist Theorem** states: fNyquist=2fmaxf_{\text{Nyquist}} = 2 f_{\max} Where:
    - fNyquistf_{\text{Nyquist}} = Minimum required sampling rate
    - fmaxf_{\max} = Highest frequency component of the input signal

Example:

- If the input signal has a maximum frequency of **100 kHz**, the ADC must have a sampling rate of at least **200 kS/s**.

📌 ADC Resolution and Bit Depth

What is Resolution?

- **Resolution** determines the number of discrete levels the ADC can output.
- Higher resolution means better accuracy and finer detail.
- Measured in **bits**.

Bit Length and Output Levels

- The number of discrete levels is determined by: 2N2^N Where:
    - NN = Number of bits in the ADC
    - 2N2^N = Number of discrete output levels**Voltage Resolution (Q) Formula**
- The smallest detectable voltage difference an ADC can measure: Q=R2NQ = \frac{R}{2^N} Where:
    - QQ = ADC Resolution (Volts per level)
    - RR = Full-scale range of the ADC (V)
    - NN = Bit depth

Example:

- If an **8-bit ADC** has a full-scale voltage range of **0-5V**, the resolution is: Q=5V28=5V256≈0.0195VQ = \frac{5V}{2^8} = \frac{5V}{256} \approx 0.0195V This means the ADC can detect **changes as small as 0.0195V**.

📌 ADC Process: Sampling, Quantization, and Encoding

1. **Sampling** – The ADC takes periodic measurements of the analog signal.
2. **Quantization** – Each sample is approximated to the nearest available discrete level.
3. **Encoding** – The quantized values are converted into **binary** for digital processing.

Example Voltage Conversion Table (3-bit ADC, 10V Range)

📌 Types of ADCs and Their Characteristics

1. Flash ADC

- **Fastest ADC type** (used in high-speed applications).
- Uses **parallel comparators** for immediate conversion.
- **Trade-off:** High cost, low resolution.

2. Wilkinson ADC

- **High-speed and high-accuracy.**
- Uses **pulse-counting techniques** for improved precision.
- More expensive than Flash ADC.

3. Integrating ADC

- **Low-cost, high-accuracy.**
- Uses **integration over time** for better precision in slow-changing signals.
- **Slow speed** makes it unsuitable for high-frequency applications.

4. Successive Approximation Register (SAR) ADC

- **Most commonly used ADC** in embedded systems.
- Balances **speed, accuracy, and cost**.
- Uses **binary search** to determine voltage levels.

📌 Accuracy and Conversion Time in ADCs

- **Resolution** → Number of discrete levels available.
- **Accuracy** → How closely the digital output matches the real-world analog signal.
- **Conversion Time** → The time required to complete the **analog-to-digital conversion**.

CHAP 3

📌 Introduction to Video Processing

Video processing refers to analyzing, manipulating, and enhancing visual information to improve its quality or extract useful data.

- **What is Video?**
  - Video consists of visual information, including both **still images** and **time-varying images**.
  - **Still Image**: Spatial intensity remains constant over time.
  - **Time-Varying Image**: Spatial intensity changes with time, known as a **spatio-temporal intensity pattern** F(x,y,t)F(x, y, t), where:
    - x,yx, y → Spatial coordinates
    - tt → Temporal variable
- **What is Processing?**
  - Involves performing operations to manipulate the video signal (e.g., compression, enhancement).
- **What is Video Processing?**
  - Refers to improving the quality of video through techniques like compression, motion analysis, enhancement, and restoration.
  - First used in military applications in the early 1960s.

📌 Why Video Processing is Important

Video processing is used in a wide range of applications, including:

- **Surveillance** (military and law enforcement)
- **Intelligent vehicle systems** (traffic control and monitoring)
- **Medical Imaging** (tracking cells, ECG/EEG analysis)
- **Event Detection** (birthdays, weddings)
- **Gesture and Behavior Recognition**
- **Sports and Marathon Tracking**
- **Person and Vehicle Re-identification**

📌 Differences Between Video and Image Processing

Image Processing	Video Processing
2D matrix	3D matrix (x, y, t)
Higher resolution	Lower resolution
No temporal data	Temporal data included

Easier processing	High computation required

Key Characteristics of Video:

- Contains **redundant information** (duplicate frames)
- Requires **real-time processing** for many applications
- Enhancing and restoring missing or distorted information is more challenging than for images

📌 Challenges in Video Processing

1. **High Computational Requirements**
2. **Reducing Redundant Information**
3. **Maintaining Quality and Clarity**
4. **Extracting Semantics from Content** (e.g., caption detection, event detection)
5. **Real-Time Application Needs**
6. **Tracking and Identification:**
    - Vehicle tracking based on license plates
    - Face tracking and person re-identification
7. **Medical Applications:**
    - ECG and EEG analysis
    - Cell tracking

📌 Introduction to Digital Video

A picture is worth a thousand words; a video is worth even more.
Digital video is a combination of **synchronized visual and audio data**.

Components of Video Data:

1. **Visual Stream:** Focus of WIG3006.
2. **Audio Stream:** Provides auditory context.

Types of Video Data:

- **Analog Video:** Traditional TV channels like RTM1, RTM2.
- **Digital Video:** Modern formats like HD ASTRO, YouTube, Blu-ray.

Data Conversion: Analog to digital conversion is possible for improved storage and transmission.

📌 Basic Concepts of Video

- **Video Frame:** A sequence of images called frames represents a video.
- **Time Interval:** Each frame is separated by a constant time interval (e.g., 1/25th of a second for 25fps).

📌 Properties of Digital Video

1. **Resolution:**
    - Frame size in pixels (width × height).
    - Example: Blu-ray > DVD > VCD
2. **Frame Rate:**
    - The number of frames per second (fps).

- Common standards:
    - **PAL:** 25 fps
    - **NTSC:** 29.97 fps

3. **Aspect Ratio:**
    - **4:3** (Traditional TV)
    - **16:9** (HDTV)
    - **1.85:1 / 2.35:1** (Cinema)
4. **Refresh Rate:** How often the screen is refreshed (Hz).
    - NTSC: 60Hz
    - PAL: 50Hz
    - Cinema: 48Hz

📌 Scanning in Video

Scanning converts a 3D signal (x,y,t)(x, y, t) into a 1D electrical signal for transmission and display.

Types of Scanning:

1. **Interlaced Scanning:**
    - Divides each frame into two fields (odd and even lines).
    - Improves motion perception and reduces flickering.
2. **Progressive Scanning:**
    - Scans the entire frame at once.
    - Produces higher image quality and is used in computer monitors and HDTVs.

Scanning Notation:

- **NTSC:** 525 lines at 59.94Hz
- **PAL:** 625 lines at 50Hz
- **ATSC:** 720p (progressive), 1080i (interlaced)

📌 NTSC vs. PAL

NTSC (North America, Japan)	PAL (Europe, Australia, Asia)
525 lines, 29.97 fps	625 lines, 25 fps
Better for fast motion	Higher resolution for still scenes
More prone to color distortion	Less color distortion

CHAP 4

1. Introduction to Digitization

Digitization is the process of converting signals from the physical world into digital form. This involves:

1. **Sampling:** Selecting specific points in time or space to represent the signal.
2. **Quantization:** Assigning discrete integer values to the amplitude of the signal at each sampling point.

Key Steps in Digitization

- **Sampling:** Converts continuous signals into discrete ones by measuring the signal at regular intervals.
- **Quantization:** Maps sampled values into finite discrete levels (e.g., 8-bit values range from 0 to 255).

2. Sampling Methods

1-D Sampling (Temporal Sampling)

- A continuous one-dimensional signal S(t)S(t) is sampled at regular intervals to form a series of discrete values.
- **Uniform Sampling:** Time intervals between samples are of equal duration.

2-D Sampling (Spatial Sampling)

- A continuous 2D function f(x,y)f(x, y) representing spatial intensity is sampled at points on a grid.
- **In Digital Video:**
  - The image is sampled on a regular rectangular grid.
  - Analog video is inherently sampled vertically at the frame rate but not horizontally.
  - CCD cameras sample images but do not inherently quantize them.

3. Digital Image Representation

- A digital image is a matrix of values, where each element corresponds to a pixel (picture element).
- Each pixel represents intensity (grayscale) or color (RGB components).

Types of Resolution in Digital Images

1. **Spatial Resolution:** Number of pixels in an image.
   - Example: A 320 × 200 image has 320 horizontal pixels and 200 vertical pixels.
   - **Formula:** Spatial Resolution=h×v\text{Spatial Resolution} = h \times v, where hh = horizontal pixels and vv = vertical pixels.
2. **Brightness Resolution:** Number of gray levels in a grayscale image.
   - Typically represented with 8-bit values, ranging from 0 (black) to 255 (white).
3. **Temporal Resolution:** Number of frames per second (fps) in a video.

4. Nyquist-Shannon Sampling Theorem

The **Nyquist-Shannon Theorem** states that perfect reconstruction of a signal is possible when the sampling rate is at least twice the maximum frequency of the signal.

- **Nyquist Frequency:** Half of the sampling rate.
- If the sampling rate is lower than the Nyquist frequency, **aliasing** occurs, resulting in loss of information.

Application to Spatial Resolution

- At least two pixels must span the smallest dimension of an object for it to be seen in an image.

5. Quantization

Quantization is the process of mapping real-valued sampled data into discrete values.

- **Higher Number of Bits = Higher Precision**
  - **8 bits:** 256 values

    - **16 bits:** 65,536 values
    - **24 bits:** 16,777,216 values (used for color images)

Examples of Quantization

- **8-bit image:** 256 gray levels
- **4-bit image:** 16 gray levels
- **2-bit image:** 4 gray levels

6. Image Resolution

1. **Spatial Resolution:**
    - Defined by the number of pixels in an image.
    - Example: A **256 × 256** image has higher spatial resolution than a **64 × 64** image.
2. **Brightness Resolution:**
    - Higher brightness resolution provides more details.
    - Most grayscale images use 8-bit values (0 to 255).
3. **Color Resolution:**
    - Determines the number of distinguishable colors.
    - **8-bit color:** 256 colors
    - **24-bit color:** True color (16.7 million colors)

7. Spatial Sampling and Temporal Sampling in Video

Spatial Sampling:

- Applies along horizontal and vertical axes of each frame.
- Determines image resolution.

Temporal Sampling:

- Applies along the time axis.
- Determines frame rate (fps), which affects motion smoothness.

8. Video Raster and Digital Video

A **video raster** is described by:

1. **Frame Rate (fs,tf_s,t)** — Frames per second.
2. **Line Number (fs,yf_s,y)** — Number of lines per frame.
3. **Samples per Line (fs,xf_s,x)** — Number of samples per line.

Temporal and Spatial Intervals

- **Temporal Interval (Δt\Delta t):** Time between frames Δt=1/fs,t\Delta t = 1 / f_s,t.
- **Vertical Interval (Δy\Delta y):** Distance between lines Δy=picture height/fs,y\Delta y = \text{picture height} / f_s,y.

9. Chrominance Subsampling

Human eyes are less sensitive to color differences than to brightness, so chrominance is often sampled at a lower rate than luminance.

Common Subsampling Formats:

1. **4:4:4:** No subsampling, full resolution for all components.
2. **4:2:2:** Chrominance components are sampled at half the rate of luminance.
3. **4:1:1:** Chrominance components are sampled at one-quarter the rate of luminance.
4. **4:2:0:** Chrominance components are sampled at half the rate both horizontally and vertically.

10. Quantization and Compression

Reducing the number of bits per sample reduces data size but also affects quality.

Quality Metrics for Video:

1. **Mean Square Error (MSE)**
2. **Peak Signal-to-Noise Ratio (PSNR)**
3. **Mean Absolute Difference (MAD)**

CHAP 5

1. Introduction to Motion Estimation

- **Motion estimation** is the process of analyzing the movement of objects in a sequence of images or video frames.
- **Types of Image Sequences**:
  - **Stereo Imaging**: Multiple cameras capturing different angles simultaneously.
  - **Video**: Single camera capturing multiple frames over time.
- **Applications**:
  - **2D**: Feature tracking, motion segmentation.
  - **3D**: Shape extraction, motion capture.
  - **Graphics**: Image stitching, animation.
  - **Robotics & Biology**: Shape inference, motion detection.

2. Correspondence Problem

- **Key Challenge**: Finding matching points in multiple frames.
- **Methods**:
  - **Small Displacements** (Video-based):
    - Uses **differential algorithms** (gradient-based methods).
    - Estimates dense correspondences.
  - **Large Displacements** (Stereo-based):
    - Uses **feature matching/correlation**.
    - Estimates sparse correspondences

3. Motion Field Computation

- **Motion Field**: Describes object displacement across frames.
- **Assumptions**:
  - Minimal changes in illumination.
  - No significant occlusion.
  - Objects do not deform excessively.

Formula: Motion vector for point displacement from frame i to j: d(x,t1,t2)=x′−xd(x, t_1, t_2) = x' - x

4. Motion Compensation and Video Compression

- **Motion Compensation**: Predicts future frames based on motion information.
- **Interframe Coding**:
  - Reduces **temporal redundancy**.
  - Common in **video compression** (e.g., H.264, MPEG).

5. Camera & Motion Models

Camera Models

1. **Perspective Projection** (Pinhole Camera Model): x=FXZ,y=FYZ$x = \frac{FX}{Z}, \quad y = \frac{FY}{Z}$
    - Objects farther from the camera appear smaller.
2. **Orthographic Projection**: x=X,y=Y$x = X, \quad y = Y$
    - Used for distant objects, assuming parallel projection.

Object Models

- **Rigid Objects**: Shape remains unchanged.
- **Flexible Objects**: Can deform (modeled using wireframes or voxels).

Motion Models

1. **Translation**:
    - Object moves by vector T=(Tx,Ty,Tz)$T = (T_x, T_y, T_z)$.
    - Formula: X′=X+T$X' = X + T$
2. **Rotation**:
    - Motion described by a **rotation matrix** [R]$[R]$.
    - Rotation around axes: Rx(θx)=[1000cosθx−sinθx0sinθxcosθx]$R_x(\theta_x) = \begin{bmatrix}1 & 0 & 0\\ 0 & \cos\theta_x & -\sin\theta_x\\ 0 & \sin\theta_x & \cos\theta_x\end{bmatrix}$ Ry(θy)=[cosθy0sinθy010−sinθy0cosθy]$R_y(\theta_y) = \begin{bmatrix}\cos\theta_y & 0 & \sin\theta_y\\ 0 & 1 & 0\\ -\sin\theta_y & 0 & \cos\theta_y\end{bmatrix}$ Rz(θz)=[cosθz−sinθz0sinθzcosθz0001]$R_z(\theta_z) = \begin{bmatrix}\cos\theta_z & -\sin\theta_z & 0\\ \sin\theta_z & \cos\theta_z & 0\\ 0 & 0 & 1\end{bmatrix}$
3. **Combination of Rotation & Translation**: X′=[R]⋅(X−C)+C+T$X' = [R] \cdot (X - C) + C + T$ where **C** is the object's center.

6. 2D Motion Models

Types of Camera Motion

1. **Track & Boom** (Translation along X, Y, Z): x′=x+FTxZ,y′=y+FTyZ$x' = x + \frac{F T_x}{Z}, \quad y' = y + \frac{F T_y}{Z}$
2. **Pan & Tilt** (Rotation around Y- and X-axes): dx=Fθy,dy=−Fθx$d_x = F \theta_y, \quad d_y = -F \theta_x$
3. **Zoom** (Focal length change): x′=ρx,y′=ρy$x' = \rho x, \quad y' = \rho y$ where ρ=F′F$\rho = \frac{F'}{F}$ (zoom factor).
4. **Roll** (Rotation around Z-axis): dx=−yθz,dy=xθz$d_x = -y \theta_z, \quad d_y = x \theta_z$

7. Motion Estimation Techniques

1. **Feature-Based Methods**:
    - Detect & track keypoints (e.g., SIFT, SURF).
    - Used for **global motion estimation**.
2. **Intensity-Based Methods**:
    - Uses **optical flow** and **constant intensity assumption**: ∂ψ∂xvx+∂ψ∂yvy+∂ψ∂t=0$\frac{\partial \psi}{\partial x} v_x + \frac{\partial \psi}{\partial y} v_y + \frac{\partial \psi}{\partial t} = 0$
    - Works at pixel level.

8. Problems in Motion Estimation

- **Occlusion & Uncovered Areas**: Some regions may be hidden or revealed between frames.
- **Constant Intensity Assumption**: Not always valid due to illumination changes.

CHAP 6

1. Introduction to Coding and Compression

- **Compression**: Reduces the size of video files while maintaining quality.
- **Why is it needed?**
  - Video and images require significant storage.
  - Limits on bandwidth and processing power.
  - Reduces redundancy in multimedia data.
- **Coding**: Represents video data compactly for efficient storage and transmission.

2. Compression Methods

A. Symbol-wise Methods (Statistical Methods)

- **Uses probability models to encode symbols efficiently**.
- More frequent symbols are assigned shorter codes.
- **Examples:**
  - Huffman Coding
  - Arithmetic Coding
- **Key Limitation**: If all symbols occur equally, no compression is achieved.

B. Dictionary Methods

- Stores commonly occurring sequences in a dictionary.
- **Types of Dictionary Coding:**
  - **Static Dictionary**: Predefined dictionary (not optimal).
  - **Semi-static Dictionary**: Custom dictionary for each text, but adds storage overhead.
  - **Adaptive Dictionary**: Builds a dictionary dynamically during compression.
- **Examples:**
  - LZ77, LZ78, LZW (Used in ZIP, PNG, and GIF formats).

C. Hybrid Methods

- Combines symbol-wise and dictionary-based compression.
- Example: **JPEG and MPEG** use both methods.

3. Symbol-wise Compression: Arithmetic Coding

- **Encodes an entire sequence as a single number**.
- More efficient than Huffman coding for certain applications.
- **Steps:**
  - Assign probability ranges to symbols.
  - Represent the sequence as a fractional number in a range.
  - Transmit the fractional number.
- **Example Encoding for “bccb” (Alphabet {a, b, c}):**
  - Assign probabilities: Pr[a] = 1/3, Pr[b] = 1/3, Pr[c] = 1/3.
  - Encode step by step, narrowing the range.
  - Final output: a fractional number within the range.
- **Decoding follows the reverse process**.

4. Dictionary-Based Compression: LZ77 Algorithm

- **Uses a sliding window approach**.
- Repeated sequences are replaced with pointers to previous occurrences.
- **Encoding Format**: <position, length, next character>
- **Example:**
  - Input: “ababab”
  - Output: <0,0,a>, <0,0,b>, <2,1,a>, <3,2,b>

5. Comparison of Methods

Method	Type	Efficiency	Complexity
Huffman Coding	Symbol-wise	Medium	Low
Arithmetic Coding	Symbol-wise	High	High
LZ77	Dictionary	High	Medium
Hybrid	Combination	Very High	High

6. Applications in Video Compression

- **JPEG**: Uses symbol-wise Huffman coding + block-based compression.
- **MPEG / H.264**:
  - **Inter-frame coding**: Reduces redundancy between frames.
  - **Motion estimation**: Tracks changes to minimize redundant storage.

CHAP 8

📌 **Video Coding and Compression - Basics**

1. Introduction to Video Compression

- **Objective**: Reduce video data size while maintaining quality.
- **Approach**: Exploit redundancy in data.
- **Benefits**:
  - Saves storage space.
  - Reduces retrieval bandwidth.
  - Enables parallel decompression and retrieval.
  - Minimizes processing time.

2. Compression Standards

- **Lossless Compression**: No loss of data (e.g., Huffman Coding, Arithmetic Coding, Lempel-Ziv, Run-Length Encoding).
- **Lossy Compression**: Discards less important information for higher compression (e.g., JPEG, MPEG, H.261, H.264).
- **Hybrid Compression**: Combination of lossless and lossy techniques (e.g., JPEG-LS, JPEG 2000, MPEG-1, MPEG-2).

Standard	Description	Compression Ratio
JPEG	Still image compression	15:1 to 50:1
H.261	Video encoding for telecommunications	100:1 to 2000:1
MPEG	Moving image compression	50:1 to 2000:1

3. Compression Techniques

A. Lossless Compression

- Perfect reconstruction of original data.
- Used for text, medical imaging, and precise data storage.
- **Examples**:
    - **Huffman Coding**: Assigns shorter codes to frequent symbols.
    - **Arithmetic Coding**: Uses probability ranges to encode data.
    - **Run-Length Encoding (RLE)**: Stores repeated sequences as (value, count) pairs.

B. Lossy Compression

- Removes redundant and less critical data.
- Used for images, audio, and video.
- **Examples**:
    - **Transform-Based Coding**: Uses DCT (Discrete Cosine Transform) in JPEG and MPEG.
    - **Quantization**: Reduces precision of less important data.
    - **Motion Compensation**: Predicts motion to reduce redundant data in frames.

C. Hybrid Compression

- **Combines both lossless and lossy methods**.
- **Examples**:
    - **JPEG 2000**: Wavelet-based image compression.
    - **MPEG-2 and H.264**: Use motion estimation + DCT + entropy coding.

4. Inter-Frame vs. Intra-Frame Compression

- **Intra-Frame Compression**:
    - Treats each frame as a standalone image (e.g., JPEG).
- **Inter-Frame Compression**:
    - Exploits similarities between consecutive frames.
    - Uses motion estimation to reduce redundancy.
    - Found in **MPEG, H.264, and HEVC**.

5. Transform Techniques

- **Inter-Component Transform**:

- Converts RGB to **YCbCr** to separate luminance from chrominance.
- Uses **Reversible Color Transform (RCT)** and **Irreversible Color Transform (ICT)**.

- **Intra-Component Transform**:
  - Uses wavelet or **DCT-based compression**.

6. Run-Length Encoding (RLE)

- **Method**:
  - Encodes repeating sequences as **(value, count)** pairs.
- **Example**:
  - Input: **1111222333**
  - Encoded: **(1,4), (2,3), (3,3)**
- **Applications**:
  - Fax transmission.
  - Zero suppression in text and images.

CHAP 9

1. Introduction to Video Compression

- **Objective**: Reduce video data size while maintaining quality.
- **Approach**: Exploit redundancy in data.
- **Benefits**:
  - Saves storage space.
  - Reduces retrieval bandwidth.
  - Enables parallel decompression and retrieval.
  - Minimizes processing time.

2. Compression Standards

- **Lossless Compression**: No loss of data (e.g., Huffman Coding, Arithmetic Coding, Lempel-Ziv, Run-Length Encoding).
- **Lossy Compression**: Discards less important information for higher compression (e.g., JPEG, MPEG, H.261, H.264).
- **Hybrid Compression**: Combination of lossless and lossy techniques (e.g., JPEG-LS, JPEG 2000, MPEG-1, MPEG-2).

Standard	Description	Compression Ratio
JPEG	Still image compression	15:1 to 50:1
H.261	Video encoding for telecommunications	100:1 to 2000:1
MPEG	Moving image compression	50:1 to 2000:1

3. Compression Techniques

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CHAP 10

Video Coding and Standards - Comprehensive Notes

1. Introduction to Video Compression Standards

- **Objective:** Achieve efficient video representation for transmission and storage.
- **Approach:** Reduce spatial and temporal redundancies in video data.
- **Benefits:**
    - Efficient storage.
    - Faster transmission rates.
    - Compatibility across devices.

2. Development of Video Compression Standards

A. By ITU-T (VCEG)

- **H.261:** Developed for ISDN transmission.
- **H.263:** Improved for low bit-rate videoconferencing.
    - Further enhanced with H.263+ and H.263++.

B. By ITU-T and MPEG (Joint Effort)

- **H.262/MPEG-2:** Combines intra-frame and inter-frame coding.
- **H.264/MPEG-4 AVC:** Advanced compression efficiency.

C. By MPEG Alone

- **MPEG-1 to MPEG-4:**
    - MPEG-1 (1993): CD-quality compression.
    - MPEG-2 (1994): Digital video broadcasting and DVDs.
    - MPEG-4 (1999): Object-based compression supporting 3D rendering.
    - MPEG-7 (2002): Multimedia content description.
    - MPEG-21 (2003): Open framework for multimedia applications.

Standard	Application	Compression Ratio
MPEG-1	CD, VHS	26:1 to 6:1
MPEG-2	DVDs, HDTV	50:1 to 200:1
MPEG-4	Streaming and mobile media	High compression

3. Key MPEG Frame Types

A. I-Frame (Intra-Frame)

- Acts as a keyframe for video.
- Independently coded using JPEG-like compression.
- Essential for random access points.

B. P-Frame (Predicted Frame)

- Encodes differences from the previous I-frame or P-frame.
- Exploits temporal redundancy.

C. B-Frame (Bi-directional Frame)

- References both past and future frames.
- Achieves the highest compression ratio.

4. Group of Pictures (GOP)

- **Definition:** Sequence of frames including I, P, and B frames.
- **M-Factor:** Number of B-frames between I and P frames.
- **GOP Example:** IBBPBBPBBIBB

5. MPEG Compression Techniques

A. Intra-Frame Compression

- DCT-based compression to reduce spatial redundancy.
- Similar to JPEG compression.

B. Inter-Frame Compression

- Block-based motion compensation.
- Exploits temporal redundancy between adjacent frames.

C. Motion Estimation

- Block matching algorithms find best matching blocks between frames.
- Reduces inter-frame differences.

6. Motion Compensation Techniques

- **Forward Prediction:** References a previous frame.
- **Bi-Directional Prediction:** Uses both past and future frames.
- **Motion Vectors:** Indicate block displacement between frames.

7. Sequence of Frames and Transmission Order

- Display Order: I, B, B, P, B, B, P...
- Transmission Order: I, P, B, B, P, B...
- Example:
    - GOP = 9; Playback order: IBBPBBPBB.
    - Transmit/Storage Order: IPBBPBB.
    - Ratio (I:P:B) = 1:2:6.

8. Block-Based Video Encoding Techniques

I-Frame Encoding:

- Color Space Conversion (RGB to YUV).
- Forward DCT and Quantization.
- Entropy Encoding.

P/B-Frame Encoding:

- Motion Estimation.
- Error Calculation and Encoding.
- Reference Frames.
- Differential Signal Encoding.

9. Scalable Video Coding (SVC)

Types of Scalability:

- **Data Partition:** Frequency scalability.
- **SNR Scalability:** Adjusts quality levels.
- **Temporal Scalability:** Frame rate adaptability.
- **Spatial Scalability:** Resolution scalability.

Fine Granularity Scalability (MPEG-4)

- Successive bit-plane coding.
- Efficient representation for dynamic quality control.

10. MPEG Compression Standards Overview

Standard	Description	Application
H.261	ISDN-based compression	Video conferencing
MPEG-2	Digital TV/DVD	Broadcasting
H.264/AVC	Advanced Video Codec	Internet streaming
MPEG-4	Mobile multimedia	Multimedia apps

11. Motion Estimation and Compensation

- **Forward Prediction:** Estimate motion using previous frame.
- **Bi-Directional Prediction:** Uses past and future frames.
- **Motion Vectors:** Displacement between current and reference blocks.
- **Block Matching Algorithms:** Search region optimization.

12. Applications of Video Compression Standards

- Video-on-Demand (VOD).
- Streaming Services.
- Videoconferencing.
- Mobile Multimedia Applications.

13. Key Concepts in Compression Standards

- **Entropy Encoding:** Huffman coding and run-length encoding (RLE).
- **Quantization:** Reduces precision of less significant information.
- **GOP Structure:** I, P, B-frame sequencing.
- **Motion Compensation:** Reduces temporal redundancy.

CHAP 11

📌 **Communication and Error Control in Video Transmission**

1. Introduction to Video Communication

- Video communication involves the transmission of multimedia data over networks.
- Applications include **video streaming, video conferencing, online broadcasting, and telecommunication**.
- **Challenges in Video Communication**:
    - Networks are unreliable (wireless, Internet congestion, etc.).
    - Video data is delay-sensitive.
    - Errors in transmission can cause video degradation.

2. Video Communication Systems

A. Simple Multimedia Server System

- Consists of storage, processing, and data servers connected via a network.
- Clients access multimedia content through a distributed architecture.
- **Components**:
    - Storage subsystem: Stores multimedia files.
    - Processor subsystem: Handles encoding and decoding.
    - Network: Transmits video data.
    - Clients: Devices that receive video data.

B. Distributed Multimedia Servers

- Multiple servers handle video content, balancing load and improving efficiency.
- Enhances scalability and fault tolerance.

3. Types of Video Transmission

- **Terrestrial TV Broadcasting**: Uses radio waves to transmit video.
- **Cable TV**: Uses wired networks for distribution.
- **Satellite TV**: Broadcasts signals via satellites.
- **Online Video**: Streaming and downloads over the Internet.
- **Types of Transmission**:
    - **Recorded**: Pre-recorded and sent on demand.
    - **Live**: Real-time transmission.
    - **Downloadable**: Stored and played later.
    - **Interactive**: User-driven content (e.g., video calls, virtual meetings).

4. Video Streaming

- A continuous flow of video data sent over the Internet.
- **Advantages**:
    - No need to download entire video before watching.
    - Real-time playback with minimal storage.
- **Requirements**:
    - A player (integrated into the browser or standalone software).
    - High bandwidth and low latency.

- **Challenges**:
  - Network congestion.
  - Packet loss and delays.

5. Error Control in Video Transmission

- **Importance**:
  - Video transmission errors degrade quality.
  - **Real-time applications** cannot rely on retransmission.
  - **Compression methods** make video more vulnerable to errors.

A. Types of Errors

- **Spatial Error Propagation**: Errors spread within the same frame.
- **Temporal Error Propagation**: Errors persist across multiple frames.
- **Drift (Reference Mismatch)**:
  - Loss in one frame leads to mismatch in later frames.
  - Encoder and decoder go out of sync.

B. Error Control Techniques

1. **Transport-Level Error Control**:
   - **Forward Error Correction (FEC)**: Adds redundancy for error detection/correction.
   - **Automatic Repeat reQuest (ARQ)**: Requests retransmission of lost packets.
2. **Error Resilient Encoding**:
   - **Sync markers**: Prevent loss of synchronization.
   - **Data partitioning**: Splits video data to isolate errors.
   - **Robust Binary Encoding**: Uses reversible encoding methods.
   - **Layered Coding with Unequal Error Protection (LC+UEP)**: Assigns different protection levels to important data.
3. **Error Concealment Techniques**:
   - **Spatial Interpolation**: Fills missing areas using nearby pixel values.
   - **Motion-Compensated Temporal Interpolation**: Copies data from previous frames.
4. **Multiple Description Coding (MDC)**:
   - Splits video into multiple streams sent over different paths.
   - Enhances robustness in unreliable networks.
5. **Path Diversity in Video Transport**:
   - Uses multiple paths to improve reliability.
   - Reduces congestion and load-balances traffic.

6. Quality of Service (QoS) in Video Communication

- **QoS Parameters**:
  - **Latency**: Delay in video playback.
  - **Jitter**: Variations in packet arrival time.
  - **Packet Loss**: Missing data affecting quality.
  - **Bandwidth**: Available data rate for transmission.

A. QoS Requirements for Different Applications

1. **Interactive Two-Way Communication**:
   - Includes **video conferencing, telephony, virtual classrooms**.
   - Requires **low latency (<150ms)**.
   - Audio and video must sync properly.

    - Low-quality video (QCIF at 5-10 fps) is acceptable.
2. **One-Way Video Streaming**:
    - Includes **TV broadcasts, online streaming**.
    - Can tolerate initial buffering delay.
    - Bitrate may vary based on network conditions.

7. Error Handling in Different Network Types

Network Type	Characteristics	Error Handling Techniques
ISDN	Reliable, 64 kbps	Low error rate, no extra correction needed
Broadband ISDN (ATM)	Uses small fixed packets	Low error rate, FEC for reliability
Internet	Variable packet loss and delay	FEC, ARQ, Path Diversity
Wireless Networks	High error rates, variable bandwidth	Strong FEC, MDC, ARQ

8. Advanced Video Error Control Techniques

1. **Encoder-Decoder Interactive Error Control**:
    - Adjusts encoding based on feedback from the decoder.
    - Uses selective intra-updates and reference picture selection.
2. **Video Transport Using Path Diversity**:
    - Transmits video over multiple network paths.
    - Reduces packet loss and improves resilience.
3. **Multiple Description Coding (MDC)**:
    - Sends multiple encoded descriptions of the same video.
    - Ensures at least some quality is retained if packets are lost.