This part of the course ...

• ... is held at Ifi, UiO ...
  (Wolfgang Leister)
• ... and at University College Karlsruhe
  (Peter Oel, Clemens Knoerzer)
The story so far ...

- Data compression
  - information theory
  - run length encoding
  - Huffman coding
  - Zif-Lempel(-Welch) algorithm
  - Arithmetic coding
- Colour coding and raster images

Overview

- Video Formats
  - MJPEG
  - H.261
  - MPEG I, II
  - MPEG TS
  - H.263
  - AVI, QuickTime
**MJPEG**

- Motion-JPEG
- Sequence of JPEG-Frames
- not a standard
- many proprietary formats
  - e.g., AVI and QuickTime
- only Baseline-JPEG
- audio track(s)

**MJPEG**

- Compression as in JPEG
- Temporal dependencies are not used.
- suitable for video cutting software:
  - cut is possible at each frame
  - no quality decrease when cutting
- Hardware support possible!
MJPEG by Parallax

- Header
  - Id / Version
  - Frames per second / number of frames
  - Width / Height
  - Bandwidth
  - Quantising factor
  - Number of Audio Tracks / Sampling Rate
  - Offset of frame index
H.261

- CCITT (Comité Consultatif International de Télécommunications et Télégraphique)
- ITU-T (International Telecommunication Union)
- Video Codec for Audiovisual Services at p x 64 kbit/s
- P64
- Developed for image telephony and video conferences

H.261

- Adapted for ISDN (p x 64 kbit/s)
- Const. data rate by feedback
- 4:2:0 Sampling (Chrominance-channels with half the resolution of luminance channel (number of rows and columns))
- Two Resolutions:
  - CIF: 352 x 288 (Common Intermediate Format)
  - QCIF: 176 x 144 (Quarter CIF)
Subsampling

- A:B:C Notion of CCIR-601
- **4:2:2** horizontal 2:1 downampling of colour channels
- **4:1:1** horizontal 4:1 downampling of colour channels
- **4:2:0** horizontal and vertical 2:1 downampling of colour channels

Example

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>C_b, C_r each</th>
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<tbody>
<tr>
<td>4:2:2</td>
<td>352 x 288</td>
<td>176 x 288</td>
</tr>
<tr>
<td>4:1:1</td>
<td>352 x 288</td>
<td>88 x 288</td>
</tr>
<tr>
<td>4:2:0</td>
<td>352 x 288</td>
<td>176 x 144</td>
</tr>
</tbody>
</table>
Video Coding

H.261

Two frame types:
- **IntraFrames**
  - Very similar to JPEG-Image (DCT, Quantising, Coding)
- **InterFrames**
  - Code differences to previous frame.
  - Movements are compensated by motion-estimation.

Intra- / InterFrames
Motion Estimation

- Left image: Hand with a tennis racket and a ball in the background.
- Right image: Hand with a tennis racket and a ball in the background.

Motion-Estimation

- Left image: Truck on a road with trees in the background.
- Right image: Truck on a road with a highlighted area indicating motion.
H.261

- Motion-Vector max. ±15 Pixels
- all DCT-Coefficients are quantised with same value
- Quantising controled by output stream (feedback).
- Quantising has dead zone

H.261 data layout
MPEG

- Motion Picture Expert Group
- ISO/IEC 11172 (MPEG-1) / 13818 (MPEG-2)
- Video / Audio compression and coding

MPEG

- Differences to H.261
  - Motion-Vectors not limited to ±15 Pixels
  - Motion-Vektors not necessarily integer numbers
  - 3 (4) Frame-Types (I-, P-, B-Frames)
  - Data stream not limited to p x 64 kbit/s.
  - Quantising of coefficients with matrix
Macro blocks

- Adjacent 8x8-Blocks of channels are joined to macro blocks.
- Depending on sub sampling several 8x8 blocks are in one macro block

Example 4:2:2
MPEG

- Frame-Types:
  - **I-Frame**: Like IntraFrames of H.261 (ca. every 15. Frame)
  - **P-Frame**: Like InterFrames of H.261 (Predicted Frame). Related to previous I or P-Frame
  - **B-Frame**: (Bidirectional predicted Frame) No equivalent of H.261. Related to previous *and* successor I- or P-Frame
I-, P- and B-Frames
Motion

- Motion compensation
  - normative part of MPEG
  - Decoder’s point of view
- Motion estimation
  - NOT normative part of MPEG
  - Encoder’s point of view
Motion Compensation

- 1 motion vector for each region
- region = macro block

\[ \forall \Rightarrow 1 \text{ motion vector per macro block} \]
- Precision: 1 Pel, \( \frac{1}{2} \) Pel
- motion vector coded differentially
  (prediction derived from preceding macro block)
- Rules for resetting motion displacements

Motion Compensation

- P-Pictures:
  - forward motion vectors
- B-Pictures:
  - forward motion vectors
  - backward motion vectors
  - if both used: average of pel values from forward and backward motion-compensated reference picture
Motion Compensation

- MPEG-2:
  - as in MPEG-1 (previous slide)
  - uses different names
  - Dual Prime Motion
    - for interlaced video
    - averaging predictions from two adjacent fields of opposite parity
Motion-Estimation

- Criterion for block matching
  - Mean Square Error
  - Mean Absolute Distortion

$$MAD(x, y) = (1/256) \sum_{i=0}^{15} \sum_{j=0}^{15} |V_n(x + i, y + i) - V_n(x + dx + i, y + dy + i)|$$

- Sum of Absolute Distortions (SAD)
- Minimization of the bitstream

Motion Estimation

- Correlation between motion vectors
Motion Estimation

- Motion displacement search algorithms
  - pel-recursive
    - iterative process
    - use intensity gradient and frame difference
  - block matching
    - compute measure of distortion
    - select vector that minimizes distortion

Motion Estimation

- Fast search algo - sparse sampling
- Variable resolution search techniques
- Statistically sparse searches
- Spatial continuity
- Telescopic search
- 3D spatial/temporal estimation
- Phase correlation
- others ...
Motion Estimation

Overview in:
Mitchell, Pennebaker, Fogg, and LeGall:
MPEG Video Compression Standard,
Chapman&Hall, 1996
p 301 ff.

Frame Order

Display order
I₀B₁B₂P₃B₄B₅P₆B₇B₈I₉...
I₀P₃B₁B₂P₆B₄B₅I₉B₇B₈...

Coding order
MPEG data layout

MPEG Encoder
MPEG Decoder

- Buffer → MUX → Q → DCT → +
- Quantizer Step Size

Side Information → Motion Vectors

Framestore and Predictor

MPEG TS
- Packetised Elementary Stream (PES)
- MPEG-2 Programme Stream
- MPEG-2 Transport Stream (TS)
  - fixed size 188 bytes packets
- DSM-CC: Digital Storage Medium Command and Control
- Service Information Tables
  - Information on streams, programmes, networks, conditional access, textual description, rating, ...

MPEG-1 compatibility
MPEG-2 TS

MPEG-2 Multiplexer

- elementary streams for one (or more) programmes
- private data
- service information
- conditional access control
- synchronisation information
- error protection
- MPEG multiplex: contiguous stream of 8-bit data bytes
- no error protection specified
- no modulation technique specified
- electrical signal levels not specified
- physical connector not specified
Presentation Unit
Access Unit

PES
Programme Stream Multiplex

- Pack Header
  - contains system clock reference
  - must occur every 0.7 sec.

MPEG-2 TS
MPEG-2 Transport Packet

MPEG-2 TS
PSI

- PSI = Programme Specific Information
- Programme Map Table (PMT)
  - what belongs to a programme?

Programme Map Table for Prog. No. 3

- PID for Programme Clock Reference = 726
- PID for video = 725
- PID for audio (English) = 57
- PID for audio (French) = 60
- PID for audio (German) = 1022
- PID for subtitle data = 123

PSI

- PSI = Programme Specific Information
- Programme Map Table (PMT)
- Programme Association Table (PAT)
  - which PMT are available?
  - PID=0
\textbf{PMT: PID=1127} \hspace{1cm} \textbf{PAT: PID=0 (always)}

- **PSI = Programme Specific Information**
- **Programme Map Table (PMT)**
- **Programme Association Table (PAT)**
- **Network Information Table (NIT)**
  - PMT=0
  - optional, content not defined by MPEG
    - channel frequencies
    - satellite transponder
    - modulation characteristics
    - service originator, service name,
PSI

- PSI = Programme Specific Information
- Programme Map Table (PMT)
- Programme Association Table (PAT)
- Network Information Table (NIT)
- Conditional Access Table (CAT)
  - scrambling system(s) in use
  - PID for conditional access management
  - PIC for entitlement information
  - not defined by MPEG

PSI

- PSI = Programme Specific Information
- Programme Map Table (PMT)
- Programme Association Table (PAT)
- Network Information Table (NIT)
- Conditional Access Table (CAT)
  - for programme streams
PSI

- Programme Map Table (PMT)
- Programme Association Table (PAT)
- Network Information Table (NIT)
- Conditional Access Table (CAT)

MPEG and IP

- MPEG is both storage and transport medium
- MPEG streams can be transported on IP
- UDP packets can be transported on MPEG
- Unidirectional application protocols
- Broadcast
- Multicast
- Unicast
Time

- Multiplexer / Decoder Clock measure time in units of 27 MHz, 42 bit
- Time Stamps expressed in units of 90 kHz, 33 bit

Programme Stream:

- System Clock Reference (SCR)
  - at least every 0.7 sec

Transport Stream:

- Programme Clock Reference (PCR)
  - at least every 0.1 sec

Presentation Time Stamp (PTS)

Decoding Time Stamp (DTS)

- temporarily stored at DTS, not shown
- I and P pictures (accessed for B pictures)
  - PTS > DTS
MPEG - I

- Resolution: 360 x 288 x 25 (CIF Eur.)
  352 x 240 x 30 (CIF US)
- Bitrate \(\leq 1,862\) Mbit/s
- Macroblocks/Frame \(\leq 396\)
- Macroblocks/Second \(\leq 9900\)
  - \((396 \times 25, 330 \times 30)\)
- No Interlace
- Audio: 2 Channels (Stereo)

MPEG - II

- Resolutions
  - low: 360 x 288 (352 x 240)
  - main: 720 x 596 (704 x 480)
  - high1440: 1440 x 1152 (HDTV 4:3)
  - high: 1920 x 1080 (HDTV 16:9)
- Bitrate: 2 - 80 Mbit/s
- Interlace Support
- 5 Audio-Channels
Data rates

<table>
<thead>
<tr>
<th>Frametyp</th>
<th>I</th>
<th>P</th>
<th>B</th>
<th>Ø</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPEG-1 SIF 1.15 Mbit/s</td>
<td>150.000</td>
<td>50.000</td>
<td>20.000</td>
<td>38.000</td>
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<tr>
<td>MPEG-2 601 4.00 Mbit/s</td>
<td>400.000</td>
<td>200.000</td>
<td>80.000</td>
<td>130.000</td>
</tr>
</tbody>
</table>

I-Distance: 15
P-Distance: 3

These are subject to another session ...
– be patient …
H.263

- ITU-T approved standard
  - “Video coding for low bit rate communication”
  - v1 1996
  - v2 1998 = H.263+; focus today
  - v3 ? H.263++/H.26L
- Unspecified, variable bit rate (<28.8 kbps)
- Developed for low delay environments

H.263 block diagram

Diagram labels:
- T: Transform
- Q: Quantizer
- P: Picture Memory with motion compensated variable delay
- CC: Coding control
- F: Flag for transmitted or not
- q: Quantizer indication
- qz: Quantizing index for transform coefficients
- v: Motion vector

Diagram: [Diagram of H.263 block diagram]
**H.263 sampling blocks**

- **4:2:0 sampling**
  - luminance $Y$ to chrominance $C_B$, $C_R$  
- **Block:**
  - 8 x 8 pixels
- **Macroblock (MB):**
  - 4 $Y$ + $C_B$ + $C_R$ blocks
- **Group of blocks (GOB):**
  - One or more rows of MBs
  - In GOB header: resynchronization

**H.263 resolutions**

- **Five standardized resolutions**
  - CIF: 352 x 288 (as in H.261)
  - QCIF: 176 x 144 (as in H.261)
  - Sub-QCIF: 128 x 96
  - 4CIF: 704 x 576 (little used?)
  - 16CIF: 1408 x 1152 (little used?)

- **Custom resolutions negotiable**
  - multiple of 4 in both directions.
H.263 frames

- Two (six) frame types:
  - I-frames: intra
  - P-frames: predictive (inter)
  - B-frames (optional): bidirectional predicted
  - PB-frames (optional): decoded B and P frame as one unit
  - EI-frames (optional): enhanced I-frame
  - EP-frames (optional): enhanced P-frame

H.263 coding

- Spatial redundancy (intra coding):
  - DCT
  - Variable length coding (Huffman)
  - Quantisation
- Temporal redundancy (inter coding):
  - Motion compensation
    - Block-based comparison (MB or block)
    - Nonintegral motion vector values (half-pixel)
  - Motion estimation
H.263 coding options (1)
• 16 modes, *negotiable* at session start:
  – Efficiency / improved picture quality (10)
    • Unrestricted Motion Vector
    • Syntax-Based Arithmetic Coding
    • Advanced Prediction!
      – Four Motion Vectors per Macroblock
      – Overlapped Block Motion Compensation
    • PB Frame
    • Advanced Intra Coding
    • Alternate Inter VLC
    • Modified Quantization
    • Deblocking Filter
    • Improved PB Frame

H.263 coding options (2)
• Error robustness (3) (lossy channel)
  – Slice-Structured
  – Reference Picture Selection
  – Independent Segment Decoding
• Scalability!
  – Temporal, signal-to-noise ratio (SNR), spatial
• Reference Picture Resampling
• Reduced Resolution Update
H.263 levels

- Preferred combination of supported options (profiles)
  - Level 1: advanced intra coding, deblocking filter, full-frame freeze, modified quantization
  - Level 2: unrestricted motion vector, slice-structured, reference picture resampling + level 1
  - Level 3: advanced prediction, improved PB frames, independent segment decoding, alternate VLC + level 2

AVI

- Audio Video Interleaved, by Microsoft Corp.
- Specialisation of RIFF (Resource Interchange File Format)
- Container-Format
- File consists of blocks (chunks)
- Each chunk characterised by 4 letters
- Format: ID (4Byte) length (4 Byte) data
- Each chunk can contain sub-chunks.
AVI

- Supported compressors:
  - Cinepack Codec by SuperMatch
  - Intel Indeo Video R2.1, R3.1 and Raw
  - Microsoft Video 1
  - Microsoft RLE
  - Motion JPEG
  - MPEG

QuickTime

- Charles Wiltgen
- Originally for Macintosh
- available for MS-windows and others
- Container-Format
- File built of blocks (tracks)
- Each block can contain sub-blocks
### QuickTime

<table>
<thead>
<tr>
<th></th>
<th>QuickTime for Macintosh 2.5</th>
<th>QuickTime for MS-Win. 2.1.1</th>
<th>QuickTime for MS-Win. 2.5</th>
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<tr>
<td>Animation</td>
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<td>r</td>
<td>r/w</td>
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<td>r</td>
<td>r/w</td>
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<tr>
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<td>r/w</td>
<td>r/w</td>
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<tr>
<td>Graphics</td>
<td>r/w</td>
<td>r</td>
<td>r/w</td>
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<td>M-JPEG A</td>
<td>r/w</td>
<td>r/w</td>
<td>r/w</td>
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<td>Photo-JPEG</td>
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</table>

### Literature

- Ming-Ting Sun, and Amy R. Reibman: *Compressed Video over Networks*, Marcel Dekker, ISBN 0-8247-9423-0, 2001, Kap. 2
Literature

- MPEG System:
  - P.A. Sarginson: "MPEG-2: Overview of the System Layer", 1996,

The End of this Lecture