High Efficiency Video Coding

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2016/10/18
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Outline

• **Video coding basics**
• **High Efficiency Video Coding**
• **Conclusion**
Digital Video

• A video is nothing but a number of frames

• Attributes
  – Height
  – Width
    1080p: 1920x1080
  – Frame rate
    • 24/30/60 fps
  – Pixel values
    • 8bits: 0~255
Digital Video

4:2:0

$W \times H = \frac{W}{2} \times \frac{H}{2} + \frac{W}{2} \times \frac{H}{2}$
Need for compression

- Uncompressed 1080p video at 24 fps
  - Pixels per frame: 1920x1080
  - Bits per pixel: 8bitsx3 (RGB)
  - 1.5 hour: $1920 \times 1080 \times 3 \times 24 \times 5400 = 806$ GB
  - Bit rate: $806 \times 8 / 5400 = 1.2$ Gbits/s

- Blue-Ray DVD
  - Read rate: 36 Mbits/s

- Video Streaming or TV Broadcast
  - Transmission rate: 1 Mbits/s to 20 Mbits/s
Compression strategies

• Compression is achieved by removing redundant information from video sequence

• Redundancy type
  – Spatial redundancy: intra prediction
  – Temporal redundancy: inter prediction
  – Perceptual redundancy: Quantization
  – Statistical Redundancy: Entropy coding
Spatial redundancy removal

• Intra prediction
  – Use the spatial neighboring blocks to predict the current block
Temporal redundancy removal (1)

- Inter prediction (frame difference)
  - Use the temporal neighboring frames to predict the current frame
Temporal redundancy removal (2)

- **Inter prediction: motion compensation**
  - Divide the frame into multiple blocks
  - For each block, find out the MV between the current block and the matching block
Picture coding types

• Intra picture (I)
  – I Picture is coded without reference to other pictures
  – First picture/Random access picture

• Inter pictures
  – Uni-directionally predicted picture: P picture
  – Bi-directionally predicted picture: B picture
Perceptual redundancy removal

• Quantization
  – Most significant bits (MSBs) are perceptually more important than least significant bits
    • 255: 11111111 (MSB: 128, LSB: 1)
  – High frequency coefficient dropping
Statistical redundancy removal

- Entropy coding (e.g. variable length coding)
  - Shorter code-words used to represent more frequent values (Huffman coding)

- Original image: 8 bits/pixel, Entropy coding: 7.14 bits/pixel

- Results more dramatic when entropy coding is applied on transformed and quantized image: 1.82 bits/pixel
Summary of the key steps in video coding

• Prediction
  – Intra prediction: spatial redundancy
  – Inter prediction: temporal redundancy

• Transform and Quantization
  – Perceptual redundancy

• Entropy Coding
  – Statistical redundancy

• In-loop filtering
  – Post-processing: Image enhancement
Outline

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High Efficiency Video Coding Encoder (1)
High Efficiency Video Coding Encoder (2)

- Steps carried out by encoder
  - Partitioning each picture into multiple units
  - Predicting each unit using inter or intra prediction, subtracting the prediction from the unit
  - Transforming and quantizing the residual
  - Entropy encoding all the information
  - In-loop filter
  - Most of the steps are based on the rate-distortion optimization
High Efficiency Video Coding decoder (1)
High Efficiency Video Coding decoder (2)

• Steps carried out by decoder
  – Entropy decoding
  – Inverse quantization and inverse transform
  – Predicting each unit and adding the prediction to the output of inverse transform to form the reconstruction
  – Reconstructing a decoded video image
  – In-loop filtering
Partition ---- Coding Tree Unit

• Each frame is firstly broken up into CTUs
• In H.264/AVC, macro-block is always 16x16
  – Each macro-block is either inter or intra coded
• In HEVC, CTU can be up to 64x64
  – CTU can have a combination of inter and intra coded blocks
  – Large block sizes can reduce the signaling overhead
  – examples
Partition----Coding Unit

- CTU divided into coding units using Quadtree based splitting
  - CU is either intra or inter mode
  - CU is the basic unit for the prediction mode
Partition—prediction unit (1)

- **CU is further split into one, two or four PUs**
  - Unlike CU, PU may only be split once

- **Intra PU**
  - The basic unit to carry intra prediction information

![Diagram showing CU and PU split](image)
Partition—prediction unit (2)

• Inter PU
  – Both symmetrical and asymmetrical partitions are supported
  – The basic unit to carry motion information
Partition---Transform Unit (1)

- TU is also specified for Coding Unit
- HEVC allows a CU to split into multiple TUs recursively to form another quadtree
Partition—Transform Unit (2)

• TU is basic unit to perform transform and quantization
  – HEVC supports DCT based 4x4, 8x8, 16x16, 32x32 integer transform
  – HEVC supports DST based 4x4 transform for intra 4x4 block

• compared to H.264/AVC
  – Achieve 5% to 10% bitrate reduction
  – 8x more computations, 16x larger transpose memory
HEVC and H.264 partition comparison

• HEVC provide more flexible partitions to divide the picture into different predictions
HEVC intra prediction (1)

• HEVC intra prediction is considered as an extension of H.264/AVC

• Each PU is predicted from neighboring image data in the same picture
  – DC prediction: average value
  – Planar prediction: bilinear interpolation
  – Directional prediction: extrapolating from neighboring pixels
HEVC intra prediction (2)

- HEVC Luma has 35 intra prediction modes
  - DC: average of neighboring pixels
  - Planar: bilinear interpolation
  - 33 angular prediction
HEVC intra prediction (3)

• HEVC Chroma has 5 intra prediction modes
  – Planar: Bilinear interpolation
  – Vertical: extrapolation from vertical pixels
  – Horizontal: extrapolation from horizontal pixels
  – DC: average
  – Derived mode: the same as the Luma
HEVC intra prediction (4)

• Reference sample smoothing (pre-processing)
  – Reduce contouring artifacts caused by edges in the reference sample arrays
  – Two modes: determined by PU size and pred mode
    • Three tap (1,2,1) smoothing filter
    • Strong linear smoothing with corner reference pixels
HEVC intra prediction (5)

- Boundary smoothing (post-processing)
  - Filter first prediction row and column with three-tap filter for DC prediction and two tap for horizontal and vertical prediction
HEVC intra prediction (6)

- Intra prediction direction coding
  - Luma
    - 35 modes
    - 3 most probable modes (0, 10, 11)
    - 32 remaining modes (5bits)
  - Chroma
    - 5 modes
    - 1bit: Derived mode
    - 2bit: remaining modes
HEVC inter prediction (1)

- Inter direction
  - Forward/backward/bidirectional prediction

- Reference frame index
  - Indicate which reference frame is used

- MV: find the position in the reference frame
  - MVs can have up to $\frac{1}{4}$ pixel accuracy
HEVC inter prediction (2)

• HEVC inter prediction
  – Obtain motion information
    • Merge mode
    • AMVP mode combined with fast motion estimation
      – Integer motion estimation
      – Fractional motion estimation
  – Use motion information to perform Motion compensation
    • Use the motion information to obtain the corresponding prediction block
    • Interpolation process
HEVC inter prediction (3)

• Merge mode
  – motion data is completely inferred
  – Merge candidate construction
    • Search over A, B, C, D, and E
    • Delete the duplicate motion information
HEVC inter prediction (4)

• Advanced Motion Vector Prediction
  – inferred only motion vector
  – MV is predicted from five spatial neighbors and one co-located temporal MV
  – Only two are finally selected
Motion estimation algorithm (1)

- Integer pixel: full search algorithm
  – Repetitive, easy for hardware implementation
Motion estimation algorithm (2)

- Fast motion estimation algorithms
  - Two dimensional logarithmic search
Motion estimation algorithm (3)

• Fast motion estimation algorithms
  – Three-step search algorithm
Motion estimation algorithm (4)

- Advanced fast motion estimation algorithms
  - H.264/AVC: EPZS
  - HEVC: TZ
  - Save 98% percent of encoding time
  - Better coding efficiency
Motion estimation algorithm (5)

• Fractional pixel motion estimation
  – Half pixel motion estimation
    • The best integer with 8 half surround
  – $\frac{1}{4}$ pixel motion estimation
    • The best half with 8 $\frac{1}{2}$ pixel surround

– D: SATD
– R: MV
Benefits of merge

• The benefits of merge
  – Save lots of head information
Motion compensation (1)

• Motion compensation
  – Fetch: Find the corresponding position
  – Interpolation: for fractional MVs
  – Weighted prediction
Motion compensation (2)

- Motion compensation
  - Horizontal interpolation (first)
  - Vertical interpolation (second)
Motion compensation(3)

- Interpolation (Based on DCTIF)
  - Balance of complexity and performance
  - Luma interpolation coefficient

\[
\begin{array}{cccccccc}
\text{Index } i & -3 & -2 & -1 & 0 & 1 & 2 & 3 & 4 \\
\text{hfilter}[i] & -1 & 4 & -11 & 40 & 40 & -11 & 4 & 1 \\
\text{qfilter}[i] & -1 & 4 & -10 & 58 & 17 & -5 & 1 & 1 \\
\end{array}
\]

- Chroma Interpolation coefficient

\[
\begin{array}{cccc}
\text{Index} & -1 & 0 & 1 & 2 \\
\text{filter1}[i] & -2 & 58 & 10 & -2 \\
\text{filter2}[i] & -4 & 54 & 16 & -2 \\
\text{filter3}[i] & -6 & 46 & 28 & -4 \\
\text{filter4}[i] & -4 & 36 & 36 & -4 \\
\end{array}
\]
HEVC transform

• HEVC supports 32x32, 16x16, 8x8 and 4x4 DCT-like transforms and 4x4 DST-like transform

• DST-like 4x4 transform is allowed only for intra
  – Intra prediction is based on the top and left neighbors. Prediction accuracy is more for the pixels located near to top/left neighbors than those away from it. DST transform is more suitable to code such kind of residuals

\[
H = \begin{bmatrix}
29 & 55 & 74 & 84 \\
74 & 74 & 0 & -74 \\
84 & -29 & -74 & 55 \\
55 & -84 & 74 & -29
\end{bmatrix}
\]
HEVC quantization

• Default: uniform quantization
  – Each position is with the same Quantization step

\[ \text{Coeff}_{\text{quant}} = \frac{\text{Coeff}}{\text{QStep}} \]

• Support explicit quantization matrix coding
  – 8x8 and 4x4 quantization matrix explicitly transmitted
  – 32x32 and 16x16 quantization matrix derived
HEVC Entropy Coding (1)

- Context adaptive binary arithmetic coding
  - Syntax element coding
  - Coefficient coding

- Entropy Coding
HEVC Entropy Coding (2)

• Binaryzation
  – Turn each syntax element to a series of bin
  – Different kinds of binary methods for different syntax elements

• Bin to bits
  – Bypass encoding: 0.5 possibility
  – Context modeling
HEVC Entropy coding (3)

- Merge Index: 3 (optional values: 0, 1, 2, 3, 4)
- Binaryzation
  - 0: 0; 1: 10; 2: 110; 3: 1110; 4: 1111
  - 1110
- Encoding
  - The first bin: using context models
    - Get the context model, encoding, update the context model
  - The remained three bins: bypass coding
HEVC Deblocking filter (1)

- **Deblocking filter**
  - Used to remove the blocking artifacts
  - Method: Modified values of p0, p1, q0, q1; p2 and q2 are optional to modify
HEVC Deblocking filter (2)

- Deblocking filter
  - Deblocking filter is applied to all samples adjacent to PU and TU boundaries
  - Granularity is 8x8 grid or higher
HEVC Deblocking filter (3)

- Deblocking strength
  - 0: no Deblocking
  - 1: weak; inter PUs
  - 2: strong; intra PUs
HEVC Sample adaptive offset (1)

• Sample adaptive offset
  – Applied after deblocking
  – Second post-processing tool after deblocking
  – Compensate the difference between the reconstructed value and original value
  – Add offset to pixels depending on their categorization (band, edge).
  – Edge offset
  – Band offset
HEVC Sample adaptive offset (2)

- Edge offset
  - Check neighbors in one of four directions
  - Based on the values of the neighbors, apply one of four offsets
HEVC Sample adaptive offset (3)

- The pixel range from 0,1,2,........255 (8-bits per pixel) is uniformly split into 32 bands
- Only 4 consecutive bands are selected by the encoder
- A fixed offset added to all samples of the same band
- A separate offset is signaled for each band
HEVC Sample adaptive offset (4)

- SAO Results
  - Smaller ringing artifacts
  - About 3% objective quality improvement
HEVC Key features (1)

- Larger and Flexible Coding Block Size
- Larger Interpolation Filter
- Sample Adaptive Offset
- Fewer Edges
- In-loop Filter
- High Throughput CABAC & Advanced Motion Vector Prediction
- Q^{-1} + T^{-1}
- More Prediction Modes
- Larger Transforms and More Sizes
- Motion Comp.
<table>
<thead>
<tr>
<th>Feature</th>
<th>High Coding Efficiency</th>
<th>High Throughput / Low Power</th>
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<tr>
<td>Larger and Flexible Coding Block Size</td>
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<td></td>
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<td>More Sophisticated Intra Prediction</td>
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<td>Larger Interpolation Filter for Motion</td>
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<td>Compensation</td>
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<td>Larger Transform Size</td>
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<td>Parallel Deblocking Filter</td>
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<td>Sample Adaptive Offset</td>
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<td>High Throughput CABAC</td>
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<td>High Level Parallel Tools</td>
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<tr>
<td>Parallel Merge/Skip</td>
<td></td>
<td>X</td>
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HEVC benefits (1)

- Subjective quality (under the same bitrate)
HEVC benefits (2)

• 2x higher compression compared to H.264
  – H.264 is the currently dominant video coding standard

• Higher throughput and lower power

• Benefits
  – Less burden on global networks
  – Easier streaming of HD video to mobile devices
  – Account for advancing screen resolution

• HEVC will provide a flexible, reliable, and robust solution to the next decade of video
HEVC test model usage

• Configuration
  – All intra: test intra case
  – Random access: best quality
  – Low delay: video conference

• Basic usage
  – Checkout the HEVC code at using SVN
    https://hevc.hhi.fraunhofer.de/svn/svn_HEVCSoftware/
  – Encoder: -c sequence.cfg –c configuration.cfg
    • Most important parameters: QP
  – Decoder: -b str.bin –o dec.yuv
Outline

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Conclusion

• We introduced some video coding basic technology

• We briefly introduced some technology for both HEVC encoder and decoder
  – Partition, intra/inter prediction, transform, quantization, CABAC, In-loop filter

• We introduced some basic usage of HEVC test model
Some useful links

• HEVC special issue: TCSVT Dec. 2012
• HEVC proposal: http://phenix.it-sudparis.eu/jct/
• JVET proposal: http://phenix.it-sudparis.eu/jvet/
• HEVC test model: https://hevc.hhi.fraunhofer.de/svn/svn_HEVCSoftware/
Thank you!

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