Versatile Video Coding –
towards the next generation of video compression

Picture Coding Symposium 2018, San Francisco, 2018-06-26
"Bridging the Gap" Invited Talk

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Outline

1. Introduction and history of video coding standardization
2. Call for Proposals on Versatile Video Coding – results
3. Tools for improved compression – some details
4. Next steps, summary and outlook
1. Introduction and history of video coding standardization

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PCS 2018 – "Bridging the Gap" Invited Talk
Jens-Rainer Ohm and Gary Sullivan
Motivation for permanent improvements in video compression

- Video is already the vast majority of data traffic (~75%)
- Video is continually increasing by resolution
  - HD existing, UHD (4Kx2K, 8Kx4K) appearing
  - Mobile services going towards HD/UHD
  - Stereo, multi-view, 360° video
- Devices available to record, display and distribute ultra-high resolutions
  - Becoming affordable for home and mobile consumers
  - Surveillance uses expanding, with remote storage and analysis
- Video has multiple dimensions to grow the data rate
  - Frame resolution, temporal resolution
  - Color resolution, bit depth
  - Multi-view
  - Visible distortion still an issue with existing networks
- Necessary video data rate grows faster than feasible network transport capacities
  - Better video compression (e.g. 50% rate of current HEVC) needed, even after availability of 5G
Video coding standardization organisations

- **ISO/IEC MPEG** = “Moving Picture Experts Group”

- **ITU-T VCEG** = “Video Coding Experts Group”

- **JVT** = “Joint Video Team” collaborative team of MPEG & VCEG, responsible for developing AVC (discontinued in 2009)

- **JCT-VC** = “Joint Collaborative Team on Video Coding” team of MPEG & VCEG, responsible for developing HEVC (established January 2010)

- **JVET** = “Joint Video Exploration Team” exploring potential for new technology beyond HEVC (established Oct. 2015) – renamed to “Joint Video Experts Team” responsible for developing VVC from April 2018
History of international video coding standardization (1985 - 2020)

ISO/IEC

H.120 (1984-1988)

Videotelephony

MPEG-1 (1993)

H.261 (1990+)

MPEG-4 Visual (1998-2001+)

H.264 / 14496-10 AVC (2003-2018+)


H.26x / 23090-3 VVC (2020-...)


8K, 360, ...

Videotelephony

Computer


H.264 / 14496-10 AVC (2003-2018+)


H.26x / 23090-3 VVC (2020-...)

H.120 (1984-1988)


8K, 360, ...
The scope of video standardization

• Only Specifications of the *Bitstream, Syntax, and Decoder* are standardized:
  • Permits optimization beyond the obvious
  • Permits complexity reduction for implementability
  • Provides *no* guarantees of quality
Hybrid Coding Concept

Basis of every standard since H.261

CTB – Coding Tree Block
ME – Motion Estimation
PB – Prediction Block
Q – Quantization
TB – Transform Block
TR – Transform
Performance history of standard generations

- **HEVC**
- **AVC**
- **H.263 + MPEG-4 Visual**
- **H.262/MPEG-2**
- **H.261**
- **JPEG**

**Bit-rate Reduction: 50%**

- **Foreman**
  - 10 Hz, QCIF
  - 100 frames
What made this happen over the years?

• **Improvements of motion compensation**
  – Variable partitions & merged partitions
  – Flexible frame referencing & combined prediction
  – Sub-sample precision and high performance sub-sample interpolation
  – More efficient vector prediction & coding, supporting large vector ranges

• **Improvements of 2D coding**
  – Efficient intra prediction and intra mode coding
  – Design of transform bases and variable transform block sizes

• **Loop filtering for artifact reduction**
  – Deblocking, sample-adaptive offset

• **Improvements of entropy coding**
  – Flexible binarization of syntax elements
  – Arithmetic coding
  – Adaptation and usage of context information

• **These are coupled with encoder optimization**
  – Rate distortion optimization – spend bits where they give best benefit in terms of distortion reduction
  – Adaptive rate control and perceptually tuned quantization
Steps towards next generation standard – Versatile Video Coding (VVC)

- Experimental software “Joint Exploration Model“ (JEM) developed by JVET
  - Intended to investigate potential for better compression beyond HEVC
  - Source code available from https://jvet.hhi.fraunhofer.de/
  - Was initially started extending HEVC software by additional compression tools, or replace existing tools (see next 3 pages)
- Substantial benefit was shown over HEVC, both in subjective quality and objective metrics
  - Proven in "Call for Evidence" (July 2017)
  - JEM was however not designed for becoming a standard (regarding all design tradeoffs)
  - Call for Proposals was issued by MPEG and VCEG (October 2017)
- Call for Proposals very successful (responses received by April 2018)
  - 32 companies in 21 proponent groups responded
  - 46 category-specific submissions: 22 in SDR, 12 each in HDR and 360° video
  - All responses clearly better than HEVC, some evidently better than JEM
  - This marked the starting point for VVC development
Steps towards next generation standard – Versatile Video Coding (VVC)

• What does "Versatile" stand for?

• VVC should be usable for many types of data
  – SDR and HDR up to extreme high resolutions
  – All kind of camera generated content
  – Computer generated content
  – Non-camera video modalities e.g. medical data
  – 360°, lightfield, depth, and volumetric video

• VVC should support flexible random and localized access
• VVC should be easily configurable for various application needs
• The core of VVC should consist only of minimum amount of necessary (and well-understood) building blocks – "clean slate" design as compared to HEVC
2. Call for Proposals on Versatile Video Coding – results

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Performance

- Submissions had to provide coded/decoded sequences
  - 4 rate points each, two constraint conditions "low delay" (LD) and "random access" (RA)
  - SDR: 5x HD (both LD and RA), 5x UHD-4K (only RA)
  - HDR: 5x HD (PQ grading), 3x UHD-4K (HLG grading)
  - 360°: 5 sequences 6K/8K for the full panorama

- Double stimulus test with two hidden anchors HEVC-HM & JEM
  - Rate points were defined such that lowest rate was typically less than "fair" quality for HEVC, but still possible to code
  - Quality was judged to be distinguishable when confidence intervals were non-overlapping
Performance

• Measured by objective performance (PSNR), best performers report >40% bit rate reduction compared to HEVC, >10% compared to JEM (for SDR case)
  – Similar ranges for HDR and 360°
  – Obviously, proposals with more elements show better performance
  – Some proposals showed similar performance as JEM with significant complexity/run time reduction
  – 2 proposals used some degree of subjective optimization, not measurable by PSNR

• Results of subjective tests generally show similar (or even better) tendency
  – Benefit over HEVC very clear
  – Benefit over JEM visible at various points
  – Proposals with subjective optimization also showing benefit in some cases
**Performance**

- **JVET-J1003:** Report of subjective evaluation contains 28 plots as shown, one per sequence.
- Count significant cases of positive/negative benefit with non-overlapping confidence interval against JEM.

Proposals ranked by MOS (per rate point)
• "Mean" and "significance-count" method suggested at least 7 proposals that were obviously better than JEM at same rate
  – Approx. 0.5 better in MOS
  – Proven subjectively better in particular for lower rates

<table>
<thead>
<tr>
<th>Mean MOS</th>
<th>Significance vs. JEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Pxx 6,53</td>
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<td>JEM 6,01</td>
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<td>Pxx 6,26</td>
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<td>Pnn 5,86</td>
</tr>
<tr>
<td>Pnn 6,11</td>
<td>HM 4,57</td>
</tr>
</tbody>
</table>

Performance SDR
### Performance HDR / 360°

- **Similar tendency in HDR and 360° categories**
- **Mostly same coding tools as in SDR provide good benefit**

<table>
<thead>
<tr>
<th>HDR</th>
<th>Mean MOS</th>
<th>–32 ... +32 Signif. vs. JEM</th>
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<td>Pxx</td>
<td>5,94</td>
<td>Pxx 2</td>
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<td>5,93</td>
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<td>Pnn 0</td>
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<td>Pnn -6</td>
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<td>HM</td>
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<table>
<thead>
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<th>–20 ... +20 Signif. vs. JEM</th>
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<tr>
<td>Pnn</td>
<td>3,45</td>
<td>Pnn -12</td>
</tr>
</tbody>
</table>

- HDR: High Dynamic Range
- 360°: 360° video
- MOS: Mean Opinion Score
- JEM: Joint Exploration Model
Performance compared to HEVC

- How often are best performing proposals *better* than HEVC at higher rate?
- Note: R1 $\succeq$ 1 Mbit/s; R2 $\succeq$ 1.6 Mbit/s; R3 $\succeq$ 2.8 Mbit/s; R4 $\succeq$ 4.6 Mbit/s

<table>
<thead>
<tr>
<th>P$_{\text{best}}$ vs HM</th>
<th>R1 vs R2</th>
<th>R1 vs R3</th>
<th>R1 vs R4</th>
<th>R2 vs R3</th>
<th>R2 vs R4</th>
<th>R3 vs R4</th>
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</thead>
<tbody>
<tr>
<td>SDR UHD</td>
<td>60%</td>
<td>40%</td>
<td>0%</td>
<td>80%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>SDR HD/RA</td>
<td>40%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>SDR HD-/LD</td>
<td>40%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td>HLG</td>
<td>67%</td>
<td>0%</td>
<td>0%</td>
<td>67%</td>
<td>0%</td>
<td>33%</td>
</tr>
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<td>20%</td>
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<tr>
<td>360°</td>
<td>40%</td>
<td>20%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>60%</td>
</tr>
<tr>
<td>Rate saving</td>
<td>$\sim$ 37.5%</td>
<td>$\sim$ 65%</td>
<td>$\sim$ 78%</td>
<td>$\sim$ 43%</td>
<td>$\sim$ 35%</td>
<td>$\sim$ 39%</td>
</tr>
</tbody>
</table>
Performance compared to HEVC

• How often is HEVC *better* than best performing proposals at lower rate?
  - Note: 1-xx% means that best performing proposal is equal or better
• Note: R1 ≡ 1 Mbit/s; R2 ≡ 1.6 Mbit/s; R3 ≡ 2.8 Mbit/s; R4 ≡ 4.6 Mbit/s

<table>
<thead>
<tr>
<th>HM vs P_best</th>
<th>R1 vs R2</th>
<th>R1 vs R3</th>
<th>R1 vs R4</th>
<th>R2 vs R3</th>
<th>R2 vs R4</th>
<th>R3 vs R4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDR UHD</td>
<td>0%</td>
<td>0%</td>
<td>60%</td>
<td>0%</td>
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<td>100%</td>
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<tr>
<td>HLG</td>
<td>0%</td>
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<td>100%</td>
<td>0%</td>
<td>67%</td>
<td>0%</td>
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<tr>
<td>PQ</td>
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<td>100%</td>
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<td>80%</td>
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</tr>
</tbody>
</table>

Rate saving: ~37.5% ~65% ~78% ~43% ~65% ~39%
Performance compared to HEVC

- The subjective quality of best performing proposals is always equal or sometimes better (~1/3 of cases) than HEVC at next higher rate point, over all categories (with approx. 40% less rate)

- The subjective quality of best performing proposals is always equal or sometimes better (~1/5 of cases) than HEVC at 2nd higher rate point, in SDR-UHD category (with approx. 65% less rate)

- Though it is not always the same proposal that performs best at a given rate point, it can be anticipated that merits of different proposals can be combined

- 50% (or more) bit rate reduction with same quality will probably be achievable by the new standard
3. Tools for improved compression – some details

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Jens-Rainer Ohm and Gary Sullivan
What is JEM?

- Exploration software that was built on top of HEVC-HM, with modifications / added elements as below
  - Not optimized for performance/complexity tradeoff (but need for keeping manageable encoder runtime)

- Block structure
  - Larger Coding Tree Unit (up to 256x256) and transforms (up to 64x64)
  - Quadtree plus binary tree (QTBT) block structure replaced quadtree structure of HEVC

- Intra prediction tools
  - 65 intra prediction directions
  - 4-tap interpolation filter for intra prediction
  - Boundary filter applied to other directions in addition to horizontal and vertical ones
  - Cross-component linear model (CCLM) prediction
  - Position dependent intra prediction combination (PDPC)

- Transform
  - Explicit multiple core transform
  - Mode dependent non-separable secondary transforms in intra coding
What is JEM? (cont.)

• Inter prediction
  – Subblock level motion vector prediction
  – Locally adaptive motion vector resolution (AMVR)
  – 1/16 pel motion vector storage accuracy
  – Overlapped block motion compensation (OBMC)
  – Local illumination compensation (LIC)
  – Affine motion prediction
  – Pattern matched motion vector derivation at decoder
  – Bi-directional optical flow (BIO) for improved motion compensation at decoder

• In-loop filters
  – Adaptive loop filter (ALF)
  – Bilateral filter

• CABAC design
  – Context model selection for transform coefficient levels
  – Multi-hypothesis probability estimation, improved initialization for context models
JEM: Quad-Tree plus Binary Tree Partitioning (QTBT)

- QTBT uses same rectangular block partitioning into coding units (CU) for mode signalling, prediction and transform
- QTBT structure starts from 128 × 128 square blocks (optionally larger or smaller) and always performs square-block split
- Binary trees starting from leaves of quad-tree (with horizontal / vertical split indication)
  → final CU can have either square or rectangular shape

JEM Intra Prediction Modes

- Concept of HEVC as basis
  - Higher number of prediction modes
  - Larger maximum block size
  - Additional position and mode dependent filtering/smoothing
- Chroma
  - Prediction modes from neighbors
  - Derived modes from collocated luma

JEM: Sub-CU based motion vector prediction

- CU: at most one set of motion parameters for each prediction direction
- Option to split large CU into sub-CUs
  - Alternative temporal motion vector prediction (ATMVP)
    - Fetch multiple sets of motion information from multiple blocks in collocated reference picture
  - Spatial-temporal motion vector prediction (STMVP)
    - Derive recursively by temporal motion vector predictor and spatial neighbouring motion vector

- ATMVP and STMVP: additional merge candidates (list extended to max 7)

JEM: Affine Motion Vector Derivation for MC

- Motion vector field (MVF) for CU, applicable MV derived for each 4 × 4 block at 1/16 pel resolution
  - Control point motion vector (CPMV)

\[
\begin{align*}
  v_x &= \left( \frac{v_{1x} - v_{0x}}{w} \right) x - \left( \frac{v_{1y} - v_{0y}}{w} \right) y + v_{0x} \\
  v_y &= \left( \frac{v_{1y} - v_{0y}}{w} \right) x + \left( \frac{v_{1x} - v_{0x}}{w} \right) y + v_{0y}
\end{align*}
\]

- AF INTER mode
  - Signalling CPMV difference from predictor
  - Block width and height ≥ 8 required
- AF MERGE mode
  - Derivation of CPMV from neighborhood

Figure from: JVET-G1001: Algorithm Description of Joint Exploration Test Model 7.
JEM: Decoder-side Motion Vector Refinement (DMVR)

- MVs of bi-prediction refined by bilateral template matching process
- Search between bilateral template and reference pictures
  ⇒ refined MV without further signaling
- Applied only with reference pictures with $\text{poc}_{\text{Ref}i} < \text{poc}_{\text{curr}} < \text{poc}_{\text{Ref}j}$
- Not applied if enabled in CU:
  - LIC,
  - Affine motion,
  - FRUC, or
  - sub-CU merge candidate

JEM: Cross-Component Linear Model Prediction (CCLM)

• Chroma samples predicted using corresponding reconstructed luma samples
  \[\text{pred}_C(i,j) = \alpha \cdot \text{rec}_L'(i,j) + \beta\]

• Parameters \(\alpha\) and \(\beta\): minimize regression error between neighbouring reconstructed luma and chroma samples around current block

• Further prediction between chroma components with updated parameters
  \[\text{pred}^*_C(i,j) = \text{pred}_C(i,j) + \alpha \cdot \text{resi}_{Cb}'(i,j)\]

Multiple model CCLM mode (MMLM)

• Neighbouring luma samples and neighbouring chroma samples classified into two groups
• Linear model for each group

**JEM Transforms**

- **Large block-size transforms** with high-frequency zeroing
  - Maximum transform size up to $128 \times 128$
  - Coefficients with column / row index $>32$ set to 0
    - Block width $>64$
    - Block height $>64$, respectively

- **Adaptive multiple core transform (AMT)**
  - Transform matrices quantized more accurately
  - Applicable for block sizes $\leq 64 \times 64$
  - Indicated by CU flag
  - Mode-dependent transform-set selection for intra prediction modes

### Transform Type

**DCT-II**

$T_i(j) = \omega_0 \cdot \sqrt{\frac{2}{N}} \cdot \cos \left( \frac{\pi \cdot i \cdot (2j + 1)}{2N} \right)$

where $\omega_0 = \left\{ \begin{array}{ll} \sqrt{\frac{2}{N}} & i = 0 \\ \frac{1}{2} & i \neq 0 \end{array} \right.$

**DCT-V**

$T_i(j) = \omega_0 \cdot \omega_1 \cdot \sqrt{\frac{2}{2N-1}} \cdot \cos \left( \frac{\pi \cdot i \cdot (2j + 1)}{2N-1} \right)$

where $\omega_0 = \left\{ \begin{array}{ll} \frac{1}{2} & i = 0 \\ \frac{1}{2} & i \neq 0 \end{array} \right.$

**DCT-VIII**

$T_i(j) = \sqrt{\frac{4}{2N+1}} \cdot \cos \left( \frac{\pi \cdot (2i + 1) \cdot (2j + 1)}{4N+2} \right)$

**DST-I**

$T_i(j) = \sqrt{\frac{2}{N+1}} \cdot \sin \left( \frac{\pi \cdot (i+1) \cdot (j+1)}{N+1} \right)$

**DST-VII**

$T_i(j) = \sqrt{\frac{4}{2N+1}} \cdot \sin \left( \frac{\pi \cdot (2i + 1) \cdot (j+1)}{2N+1} \right)$

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JEM: Mode-Dependent Non-separable Secondary Transforms (MDNSST)

- Motivation
  - Remaining correlation between coefficients after primary transform!
  - Dependency on intra prediction mode!
- Only applied to the low frequency coefficients after the primary transform
  - For blocks $\geq 8 \times 8$, application of $8 \times 8$ transform to lowest frequency coefficients of primary transform
  - For blocks $< 8 \times 8$, application of $4 \times 4$ transform to lowest frequency coefficients of primary transform
- Implementation by Hypercube-Givens Transform (HyGT)
- Two rounds for $4 \times 4$, four rounds for $8 \times 8$ secondary transforms

$$t_m = x_m \cos \theta - x_n \sin \theta$$
$$t_n = x_m \sin \theta + x_n \cos \theta$$

JEM: Geometry transform based adaptive loop filter (GALF)

- **Luma component**
  - 25 filters available for each 2×2 block, based on direction and activity of local gradients
  - Diamond filter shapes (3 × 3, 5 × 5, 7 × 7)
  - Classification into 25 classes, based on
    - Activitiy index
    - Directionality index
- **Chroma components**
  - Diamond filter shape 5 × 5
  - No classification
  - Single set of filter coefficients
  - Geometric transformations based on data from classification
    - Transpose, vertical flip, rotation
- Filter coefficients signaled with 1st CTU, FIFO buffering for temporal prediction in inter pictures, 16 candidate sets for intra pictures
JEM status / performance

• By mid of 2017, JEM had reached substantial improvement over HM
  – roughly 30% average bit rate reduction for inter coding (random access configuration)
  – roughly 20% for intra-only coding (without motion comp.)

• Subjective tests unveiled that this may even translate into higher visual gains (see JVET-G1004)
  – Mission accomplished: No further development performed afterwards (except bug fixing)
  – JEM was used as additional (well understood) anchor in Call for Proposals ...
  – ... waiting for things to come ...
What was proposed in CfP?

• In terms of large architecture: Most proposals similar, no deviation from hybrid coding mainstream
• Most improvements from further refinements of well-known building blocks of HEVC and JEM
  – Partitioning: Multi-type tree (Quad/binary/ternary), and finer
  – Intra prediction using
    ▪ directional modes, DC and planar
    ▪ sample smoothing with various adaptation methods
    ▪ inheritance of chroma modes and chroma sample prediction from luma
  – Inter prediction using advanced motion vector prediction, affine models, sub-block partitioning
  – Switchable primary transforms, mostly DCT/DST variants
  – Secondary transforms targeting specific prediction residual characteristics
  – Adaptive loop filter based on local classification, some new variants
  – Some new elements for quantization / context-adaptive arithmetic coding
What was proposed in CfP?

• Compression-improving tools:
  – Template matching tools (decoder side) for purposes of mode/MV derivation and sample prediction both in intra and inter coding
  – Finer partitioning: Asymmetric rectangular, geometric/wedge
  – Enlarged intra reference area & intra block copy
  – Additional non-linear, de-noising and statistics-based loop filters / prediction filters
  – Neural networks for intra prediction, loop filtering, upsampling

• HDR specific:
  – New adaptive reshaping and quantization, also in-loop
  – HDR-specific modifications of existing tools, e.g. deblocking

• 360° video specific:
  – Variants of projection formats, geometry-corrected face boundary padding
  – Modification and disabling of existing tools at face boundaries
What was new in proposals?

- Simple multi-type tree split was used in several proposals, can be alternated ternary/binary split originating from quadtree leaf.

- Further proposed variants of partitioning included
  - Asymmetric rectangular binary split modes
  - Diagonal (wedge-shaped) binary split modes

(source: JVET-J1002)
4. Next steps, summary and outlook

Versatile Video Coding – towards the next generation of video compression

PCS 2018 – "Bridging the Gap" Invited Talk
Jens-Rainer Ohm and Gary Sullivan
VVC Test Model and Benchmark Set

- **VVC Working Draft 1 / Test Model 1 (VTM1)**: basic approach built on "reduced HEVC" starting point

- **VTM Block structure**
  - Unified multi-type tree (binary/ternary splits after quad-tree, coding block unites prediction and transform)
  - CTU size 128x128, rectangular blocks (dyadic sizes), smallest luma size 4x4
  - Maximum transform size 64x64

- **VTM: Some removed elements of HEVC:**
  - Mode dependent transform (DST-VII), mode dependent scan
  - Strong intra smoothing
  - Sign data hiding in transform coding
  - Unnecessary high-level syntax (e.g. VPS)
  - Tiles and wavefront
  - Quantization weighting

- **Benchmark Set** defined in addition to VTM, including the following well-known JEM tools:
  - 65 intra prediction modes
  - Coefficient coding
  - AMT + 4x4 NSST
  - Affine motion
  - Geometry transformation based adaptive loop filter (GALF)
  - Subblock merge candidate (ATMVP)
  - Adaptive motion vector precision
  - Decoder motion vector refinement
  - LM Chroma mode

Purpose: testing benefit of technology against better performing set
Performance of VTM and BMS compared to HEVC

- PSNR-based CTC BD-Rate savings relative to HEVC reference software (10 bit)

<table>
<thead>
<tr>
<th>vs HM16.18</th>
<th>VTM</th>
<th>BMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4k UHD</td>
<td>10%</td>
<td>28%</td>
</tr>
<tr>
<td>1080p</td>
<td>8%</td>
<td>22%</td>
</tr>
<tr>
<td>WVGA</td>
<td>6%</td>
<td>19%</td>
</tr>
<tr>
<td>Average</td>
<td>8%</td>
<td>23%</td>
</tr>
<tr>
<td>Decode time</td>
<td>0.8×</td>
<td>2×</td>
</tr>
<tr>
<td>Encode time</td>
<td>2×</td>
<td>9×</td>
</tr>
</tbody>
</table>
Documents issued after CfP Results

- Report of Results from the Call for Proposals on Video Compression with Capability beyond HEVC (JVET-J1003)
  - Documentation of results per sequence, marking HM and JEM anchors, not identifying individual proponents
  - Assessment of qualitative (and as far as possible quantitative) benefit of submitted technology compared to anchors
- Working Draft 1 of Versatile Video Coding (JVET-J1001)
  - "Reduced" HEVC plus quad/binary/ternary tree structure
- Test Model 1 of Versatile Video Coding (VTM 1) (JVET-J1002)
  - Corresponding encoder and algorithm description
Core Experiments defined by JVET

• CE1: Partitioning
• CE2: In-loop filters
• CE3: Intra prediction and mode coding
• CE4: Inter prediction and MV coding
• CE5: Arithmetic coding engine
• CE6: Transforms and transform signalling
• CE7: Quantization and coefficient coding
• CE8: Current picture referencing
• CE9: Decoder side MV derivation
• CE10: Combined and multi-hypothesis prediction
• CE11: Composite reference pictures
• CE12: Mapping for HDR content
• CE13: Projection formats
Summary and Outlook

• Video is a lively area of research, major and ongoing progress in standardization

• Though HEVC has demonstrated significant technical and performance advance and is currently ramping up in markets: The work of JVET has demonstrated that significant improvement of compression beyond HEVC is possible
  – Development of experimental JEM platform demonstrated initial benefit
  – Successful Call for Proposals unveiled that even better performance is possible
  – First steps towards VVC by establishing a first draft text and test model

• This is only the beginning
  – Roughly 50% bit rate reduction with same subjective quality as HEVC can probably be reached
  – Rigid process (Core Experiments) just started to establish a reasonable tool combination under complexity/performance/other-acceptability constraints
  – Additional benefit may come from other emerging technology, e.g. deep learning / CNN – if they pass the criteria of bullet points above
Further Information

• Document archives (publicly accessible)
  – http://phenix.it-sudparis.eu/jct
  – http://phenix.it-sudparis.eu/jvet
  – http://ftp3.itu.ch/av-arch/jvet-site

• Software for VTM, HEVC, JEM, and 360 Video (publicly accessible)
  – https://jvet.hhi.fraunhofer.de/svn/svn_VVCSoftware_<VTM|BMS>
  – https://hevc.hhi.fraunhofer.de/svn/svn_HEVCSoftware/
  – https://jvet.hhi.fraunhofer.de/svn/svn_HMJEMSoftware/
  – https://jvet.hhi.fraunhofer.de/svn/svn_360Lib/