2015 Visual Communications and Image Processing

HEVC Screen Content Coding (SCC) – Standardization and Technologies

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Singapore

Outline

Part I – Standardization

- Introduction
- From HEVC to SCC Extensions
- HEVC and Range Extensions

Part II – Technologies

- SCC Extensions
- Compression Performance
- Open Research Topics

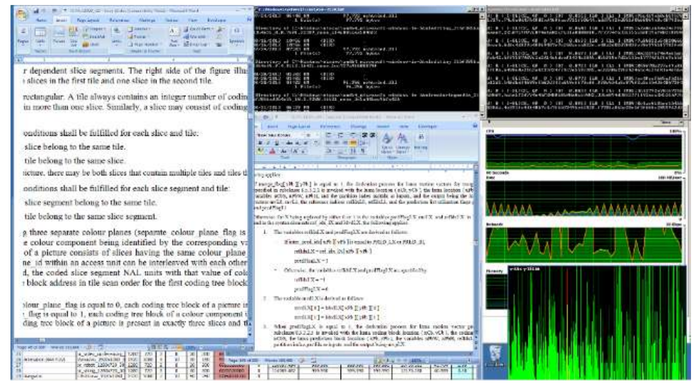
Wen-Hsiao Peng

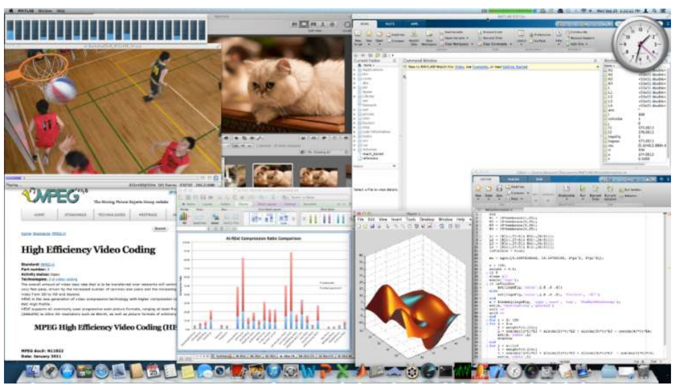
- 2015 -- : **Visiting Scholar**, IBM T. J. Watson, New York, US
- 2006 -- : Assistant/**Associate Professor**, Nat'l Chiao Tung Univ., CS Dept.
- 2005 : **Ph.D. in EE**, Nat'l Chiao Tung Univ., Taiwan
- 2013 -- : **IEEE Senior Member**
- 2009 -- : **Technical Committee Member**, IEEE CASS Visual Signal Processing and Communications (VSPC) & Multimedia Systems and Applications (MSA)
- 2003 -- : **ISO/IEC MPEG Delegate**, Taiwan Team Coordinator
- 2015 -- : **Guest Editor**, IEEE J. Emerg. Sel. Topics in Circuits and Systems
- 2006 -- : **TPC Co-Chair/Member/Area Chair** for IEEE VCIP, ISCAS, ICME, etc.
- 2000 -- 2001: **Intel Microprocessor Research Lab**, Santa Clara, US

Screen Content

- The type of content commonly seen on computer displays or mobile devices

Computer graphics and text with motion





Mixture of natural video and graphics/text

Computer-generated animation content

Screen Content "Coding"

- Encoding screen visuals in the form of video to facilitate transmission and storage
- Treating text/graphics as pixel data for platform independent rendering

Applications

- Wireless display, cloud gaming, desktop sharing and collaboration, PC-over-IP, etc.

Desktop Collaboration

Cloud Gaming

Second Screen

Screen Sharing

Challenges (1/2)

- Mixture of computer-generated and camera-captured content with distinct attributes

- **Computer-generated** content (e.g. text, graphics)
  - Noise-free, discrete-tone, thin lines, sharp edges

  → Structure and detail

- **Camera-captured** content (e.g. natural images)
  - Noisy, continuous-tone, complex texture

  → Smoothness

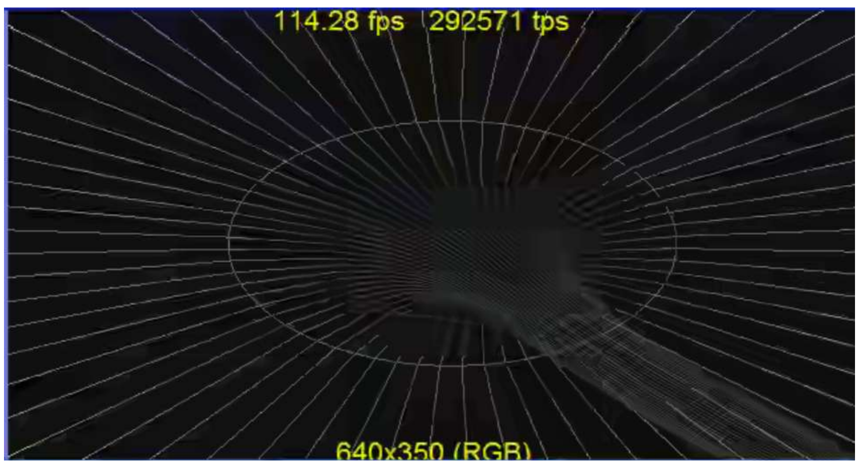
Challenges (2/2)

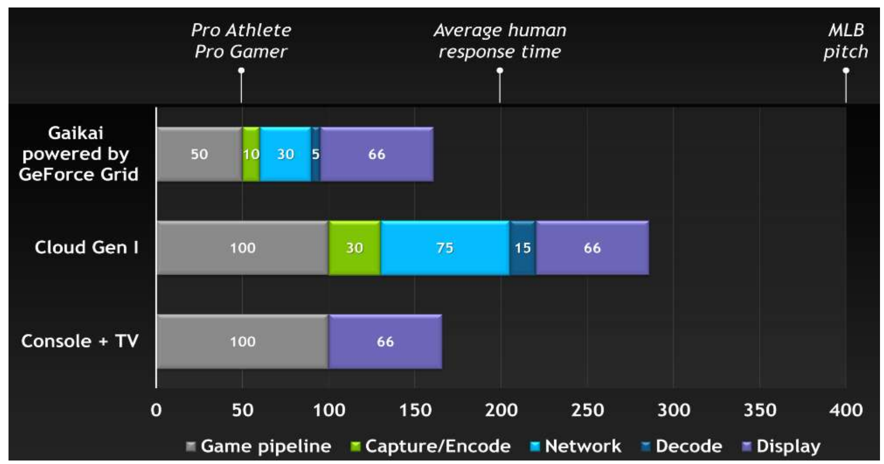
- Varied level of distortion sensitivity in different types of content

  → Artifacts in synthetic areas easily visible

- Usually stringent low-delay requirements

  → Cloud gaming, screen sharing, etc.

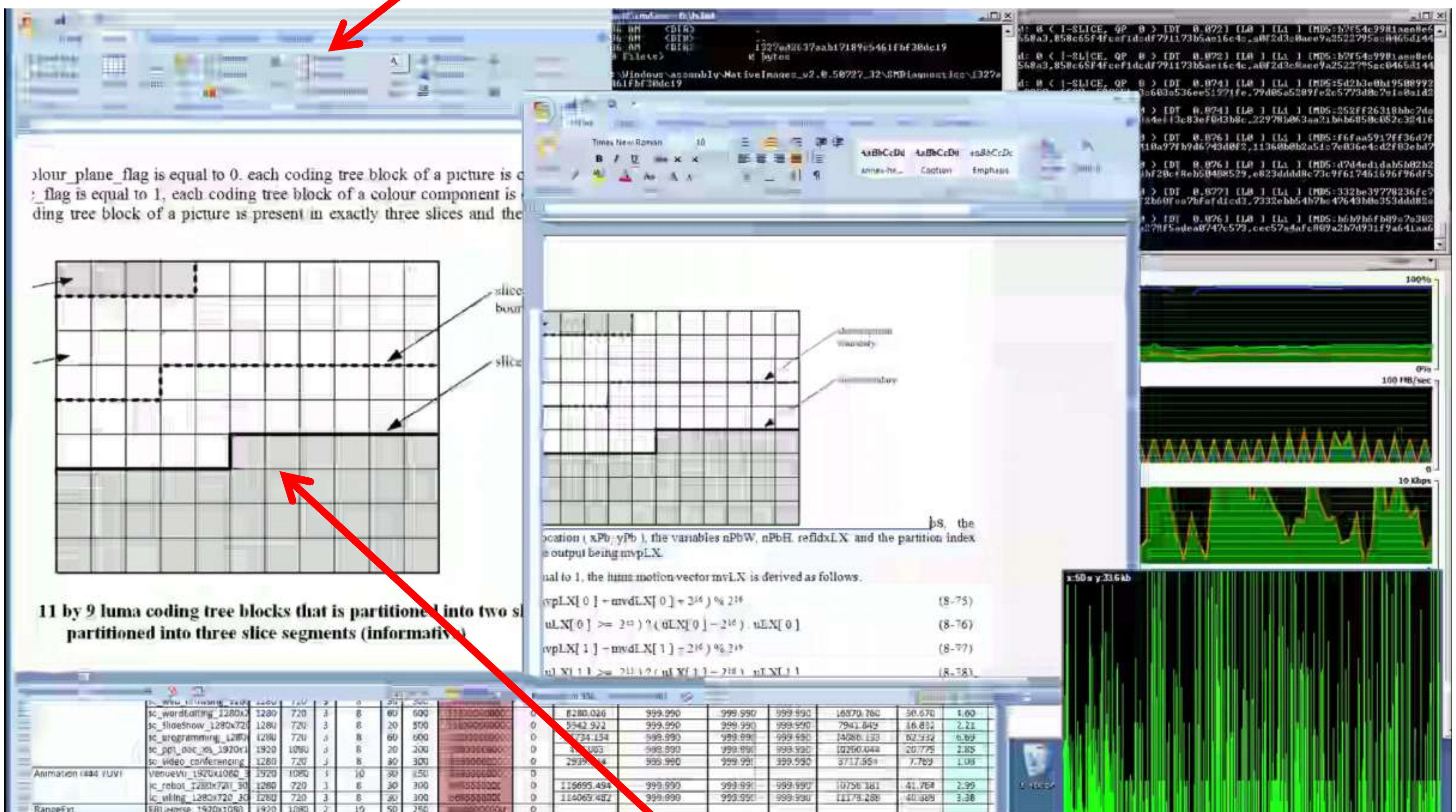




NVIDIA GeForce GRID - http://www.eurogamer.net/articles/digitalfoundry-geforce-grid-cloud-performance

Result with hybrid-based codecs

Illegible details

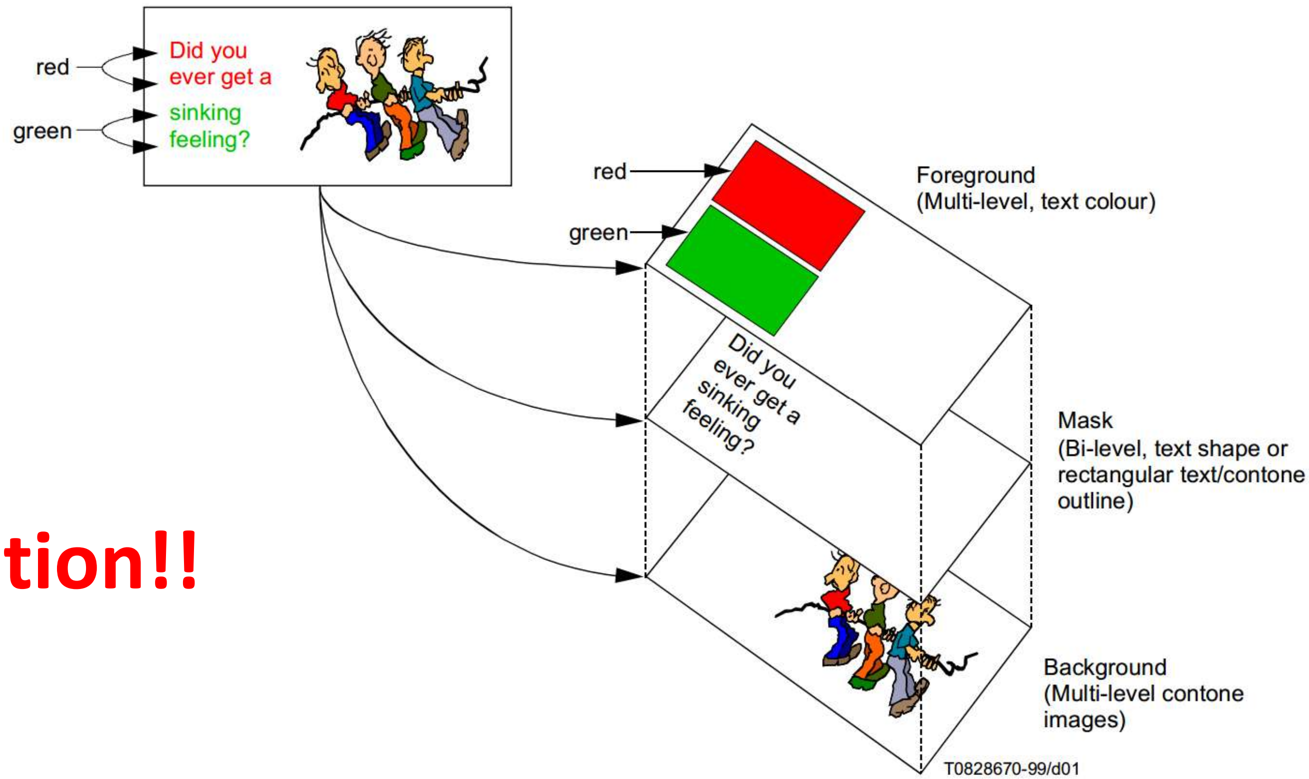


Ringing artifacts

1920x1080@60Hz: 43Mbps (All Intra)
PSNR-Y= 28dB

Existing Solutions (1/2)

- Layer-based methods – coding different types of content in separate layers



Segmentation!!

ITU-T T.44 Mixed Raster Content (MRC), 1999, 2005

Existing Solutions (2/2)

- Block-based methods

  1) Classification – pictorial, text/graphics

  2) Block-adaptive coding

  -- **Pictorial:** hybrid-based coding (trans. + pred.)

  -- **Text/graphics:** palette coding, shape primitives, LZ coding, QP-adaptation, etc.

- Line-based methods → low-delay and low-cost applications (e.g. display stream compression)

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- Open Research Topics

Standards Organizations

- ISO/IEC **Moving Picture Experts Group (MPEG)**

  -- MPEG-1/2/4, MPEG-4 AVC, MPEG-H HEVC

- ITU-T **Video Coding Experts Group (VCEG)**

  -- H.261, H.263, H.264, H.265

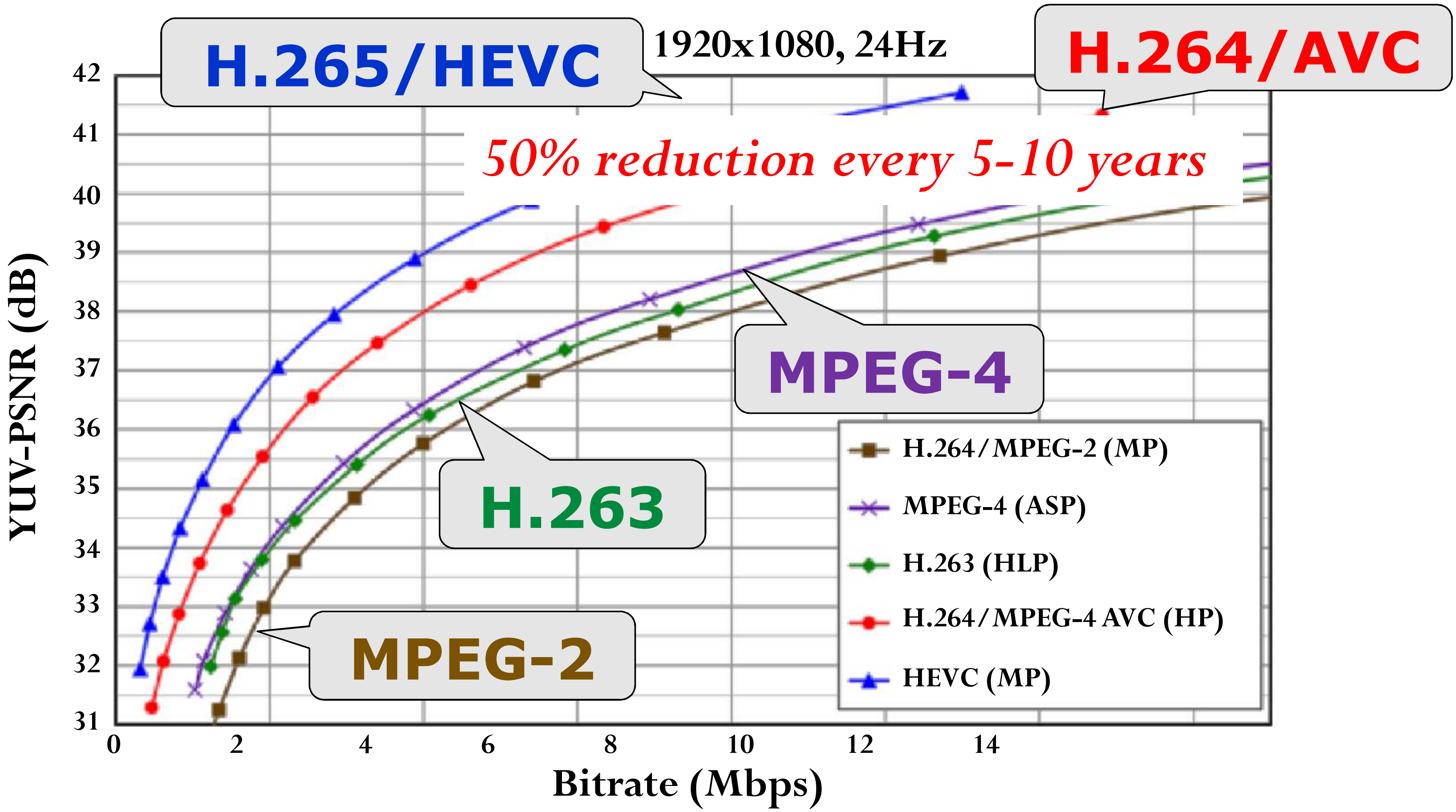
- Joint Collaborative Team on Video Coding (JCT-VC)

  ISO – International Standardization Organization
  IEC – International Electrotechnical Commission
  ITU – International Telecommunication Union

Progress of Video Coding Standards

- **H.261** (CCITT/ITU;**1984, 88, 90**) – **videoconf.**
- MPEG-1 (1988 -- 92) – VCD
- **MPEG-2 (1990 -- 94) – DVD, DTV**
- MPEG-4 Part 2 (1992 -- 99) – Internet, WL
- H.263 (1993 -- 95; ver.3: 2000) – WL
- **AVC/H.264** (1998 -- 03) – **WL, HD-DVD**
- AVC Amd. (2003 -- 2007) – Scalable Video Coding
- AVC Amd. (-- 2008) – Multiview Video Coding
- **HEVC/H.265 v1** (**2010 - 13**) – **Ultra-HD Video**
- HEVC v2 (2014) – Range, Scalability, Multiview Extensions
- **HEVC v3 (2016)** – **Screen Content Coding Extensions**

Coding Efficiency Evolution



J.-R. Ohm, G. J. Sullivan, H. Schwarz, T. K. Tan, and T. Wiegand, "Comparison of the Coding Efficiency of Video Coding Standards—Including High Efficiency Video Coding (HEVC)", IEEE Trans. CSVT, Dec., 2012

The MPEG Process

1. **Exploration**

   Search for new technology

2. **Requirements**

   Establish work scope

   Call for Proposals (CfP)

3. **Competitive phase**

   Do Homework

   Response to CfP

   Initial technology selection

4. **Collaborative phase**

   Core Experiments

   Working Drafts

5. **Standardization**

   Ballots

   National Body Comments

6. **Amendment**

   Adding new technology

7. **Corrigenda**

   Corrective actions

8. **New subdivisions**

   Add new non-compatible technology

High Efficiency Video Coding (HEVC)

- The latest standard developed by JCT-VC (2013)
- **Goal:** To offer substantial improvements over AVC in coding camera-view **ultra-HD video** (e.g. 4k)
- Exploration started in 2005
- Call-for-Proposals (2010) – 27 proposals
- Screen content – not major focus, only 1 tool

HEVC Version 2

- HEVC version 2, 2013 - 2015
- Range Extensions (RExt) – added support for
  - Monochrome, 4:4:4, 4:2:2, and RGB formats
  - Higher bit depths (up to 16)
  - Improved lossless and near lossless coding
  - Screen content coding – limited support
- Scalability & Multi-view Extensions

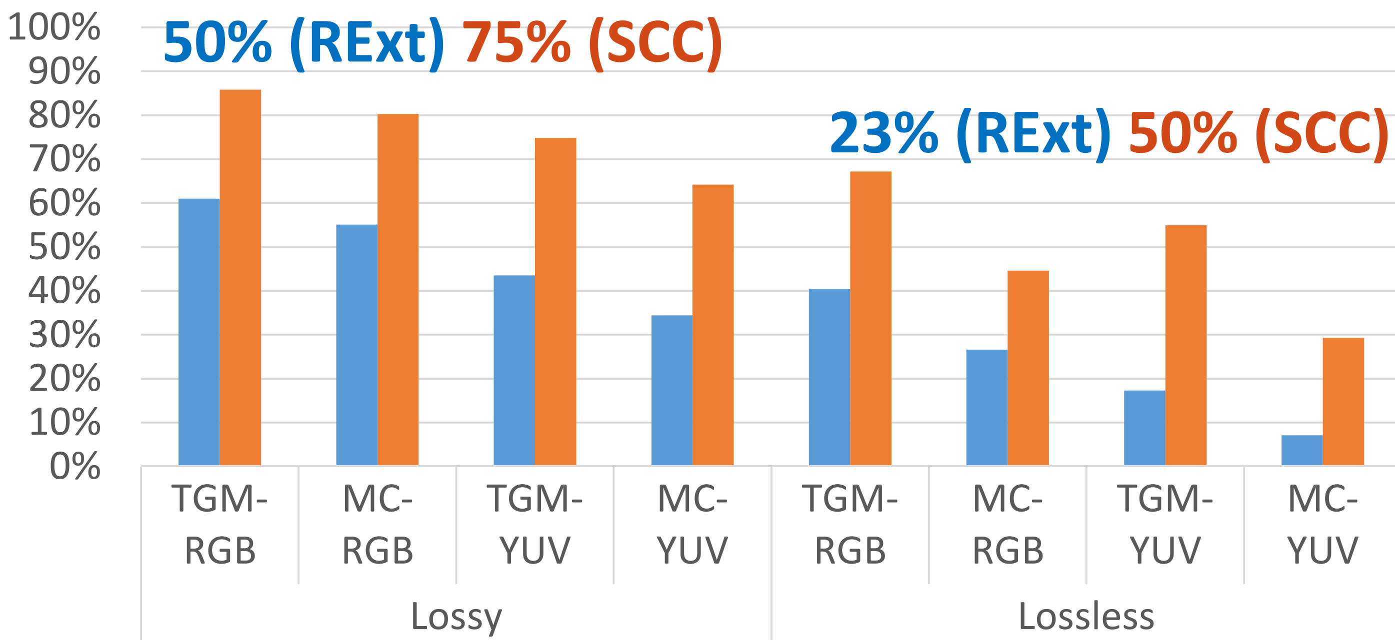
HEVC Version 3

- HEVC version 3 (**in progress**)
- Screen Content Coding (SCC) Extensions, 2016
  - Screen, mixed, and animation content
  - RGB/YUV in 4:4:4/4:2:0, 8-10 bits
  - Call-for-Proposals (2014) – 7 proposals
  - Tools designed specifically for SCC
- Others (e.g. 3D)

	HEVC v1	HEVC-RExt	HEVC-SCC
Target Input	Camera-view Content	Camera-view Content	**Screen & Mixed Content**
Color Space	YUV	YUV, **RGB**	YUV, **RGB**
Color Format	4:2:0	4:2:0, **Monochrome, 4:2:2, 4:4:4**	4:2:0, **4:4:4**
Bit Depth	8 – 10	>10 (Up to 16)	8 – 10
SCC Tools	1. Transform Skip	1. Transform Skip 2. Residual Rotation 3. Residual DPCM 4. Cross-component Prediction	1. Transform Skip 2. Residual Rotation 3. Residual DPCM 4. Cross-component Prediction 5. Intra Block Copy 6. Palette Mode 7. Adaptive Color Transform 8. Adaptive Motion Vector Resolution

HEVC-RExt, HEVC-SCC vs. AVC (1/2)

All Intra

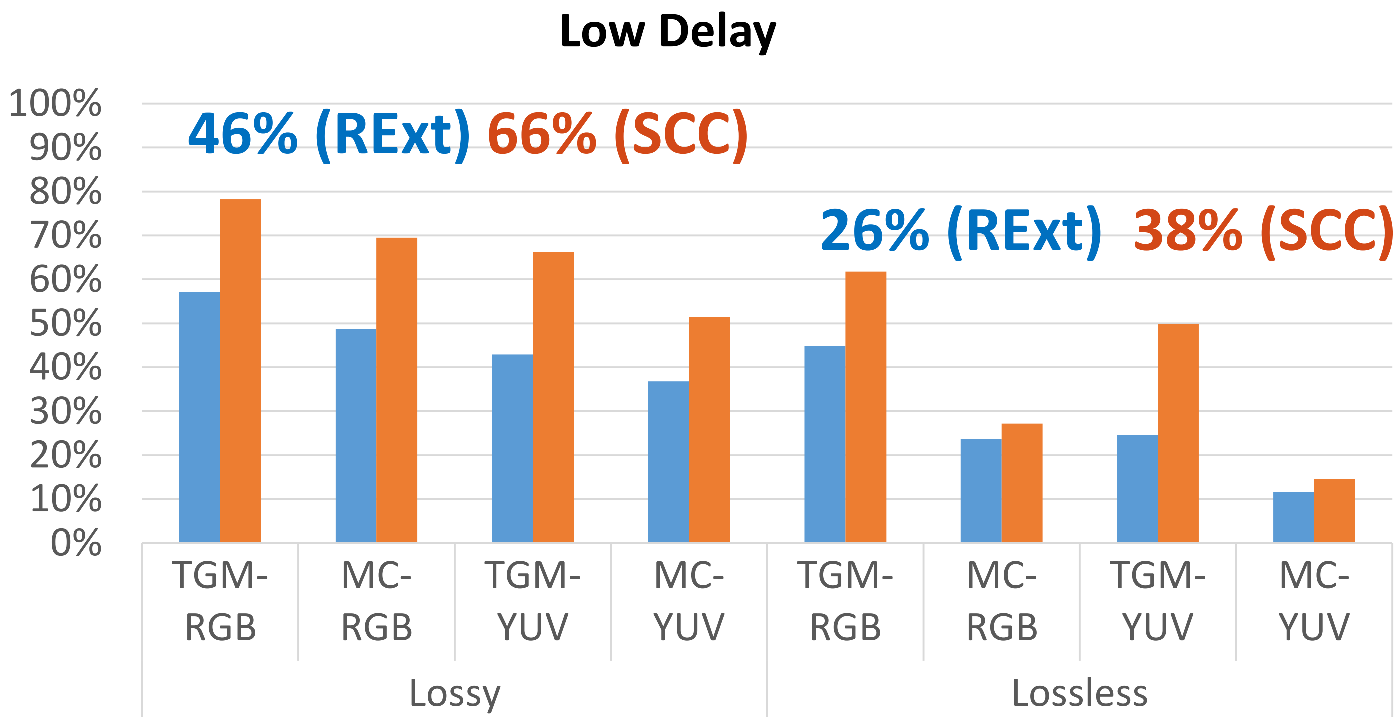


	Lossy TGM-RGB	Lossy MC-RGB	Lossy TGM-YUV	Lossy MC-YUV	Lossless TGM-RGB	Lossless MC-RGB	Lossless TGM-YUV	Lossless MC-YUV
AI RExt	61.00%	55.10%	43.50%	34.40%	40.44%	26.57%	17.25%	7.11%
AI SCC	85.80%	80.30%	74.80%	64.20%	67.20%	44.60%	54.90%	29.30%

■ AI RExt ■ AI SCC

AVC (JM-19.0) -- RExt (HM-16.6) -- SCC (SCM-5.2)

HEVC-RExt, HEVC-SCC vs. AVC (2/2)

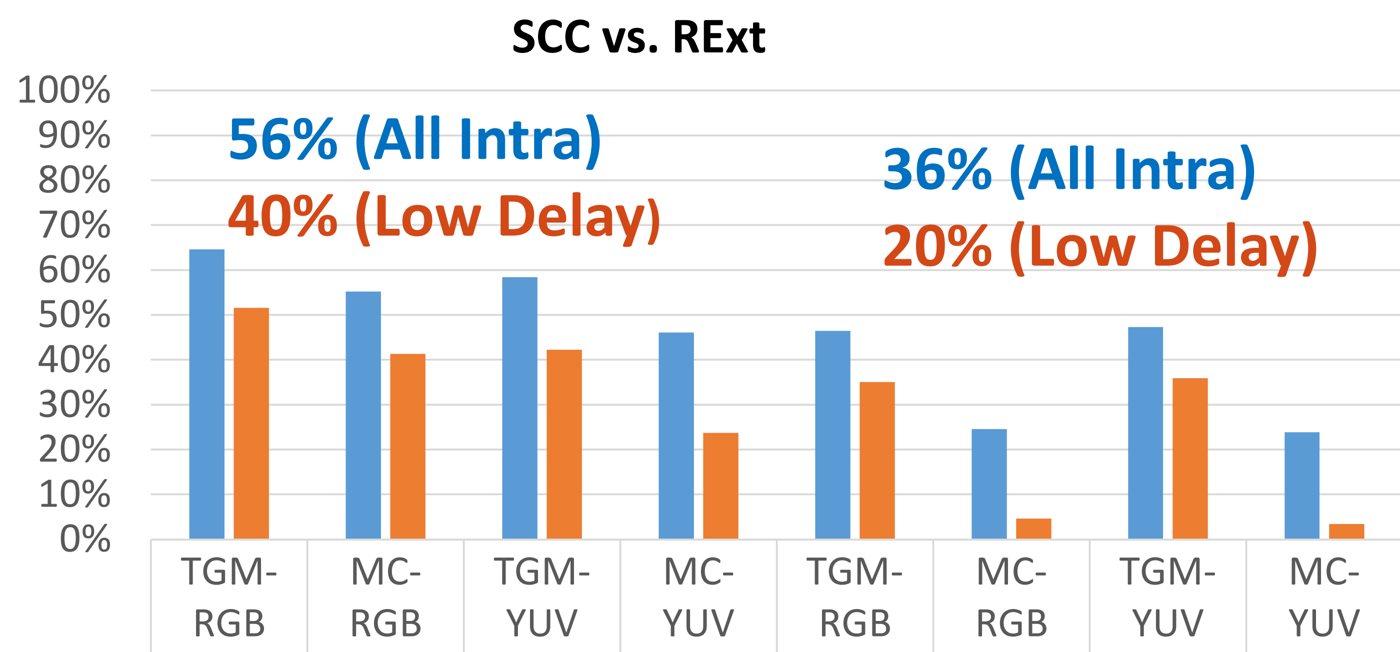


	Lossy				Lossless			
	TGM-RGB	MC-RGB	TGM-YUV	MC-YUV	TGM-RGB	MC-RGB	TGM-YUV	MC-YUV
LB RExt	57.20%	48.70%	42.90%	36.80%	44.85%	23.68%	24.56%	11.59%
LB SCC	78.20%	69.50%	66.30%	51.40%	61.80%	27.20%	49.90%	14.60%

LB RExt LB SCC

AVC (JM-19.0) -- RExt (HM-16.6) -- SCC (SCM-5.2)

HEVC-SCC vs. HEVC-RExt



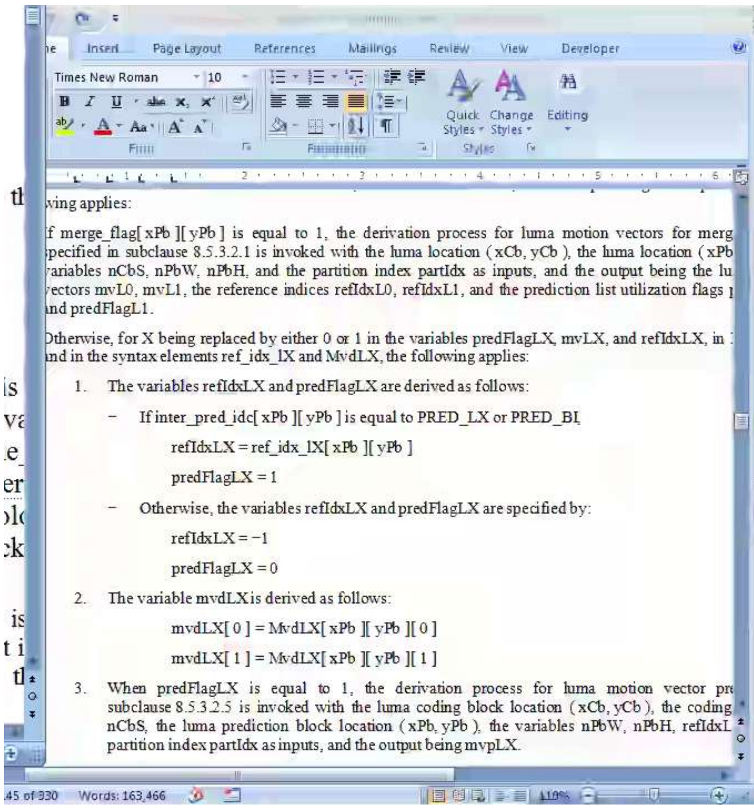
	Lossy				Lossless			
	TGM-RGB	MC-RGB	TGM-YUV	MC-YUV	TGM-RGB	MC-RGB	TGM-YUV	MC-YUV
All Intra	64.60%	55.20%	58.40%	46.10%	46.43%	24.57%	47.29%	23.87%
Low Delay	51.60%	41.30%	42.20%	23.70%	35.00%	4.63%	35.89%	3.43%

All Intra　Low Delay

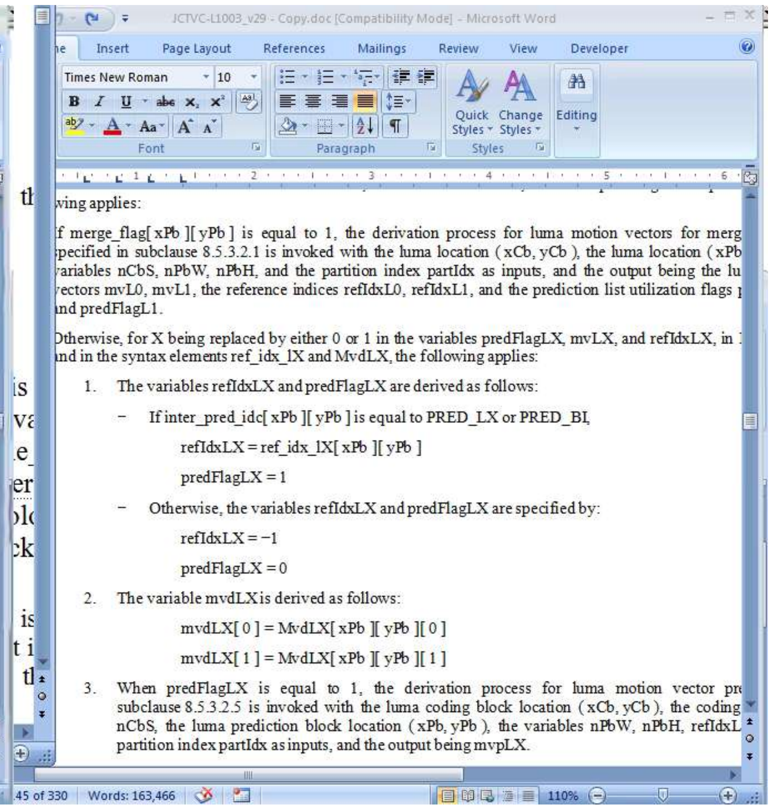
RExt (HM-16.6) -- SCC (SCM-5.2)

Subjective Quality Comparison

HEVC RExt



HEVC SCC



Desktop: 1920x1080_60Hz (All Intra)

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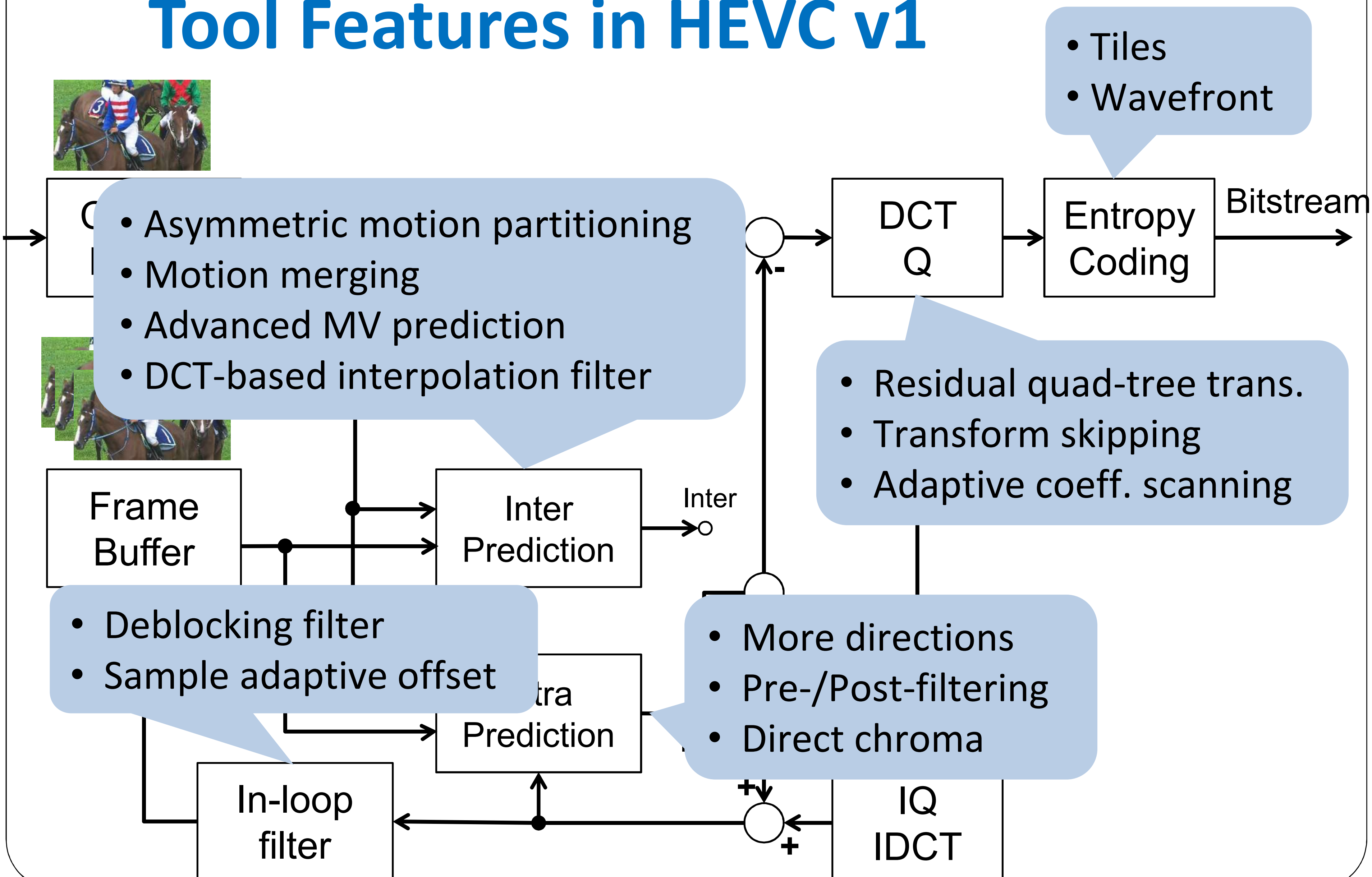
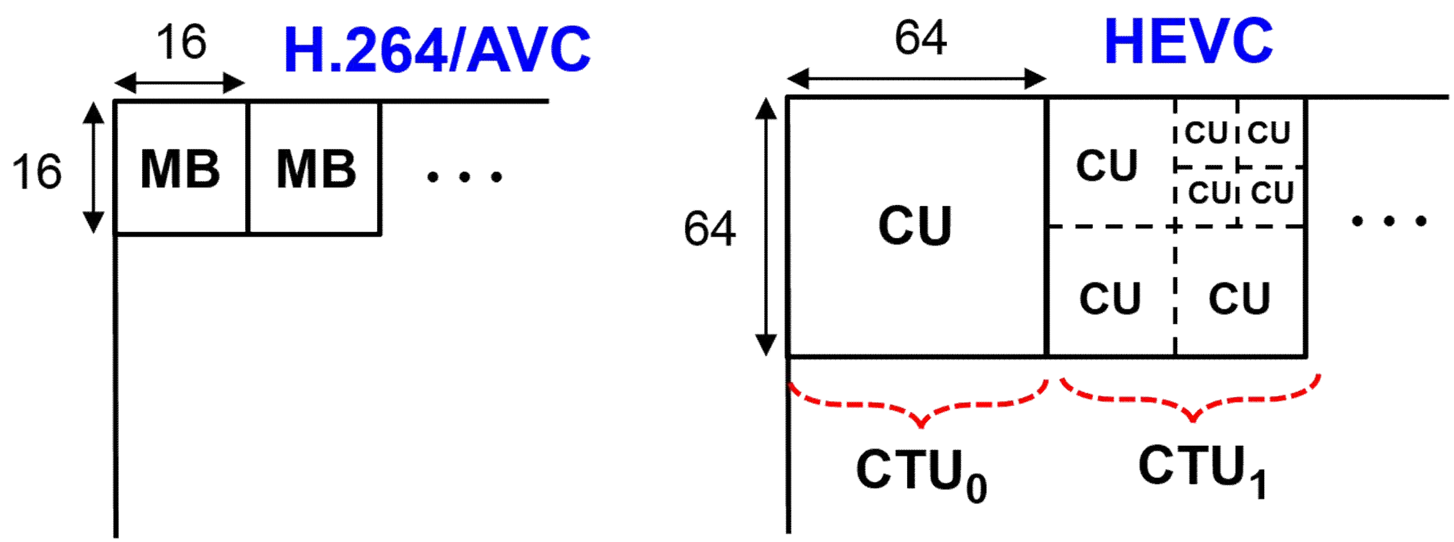
Tool Features in HEVC v1



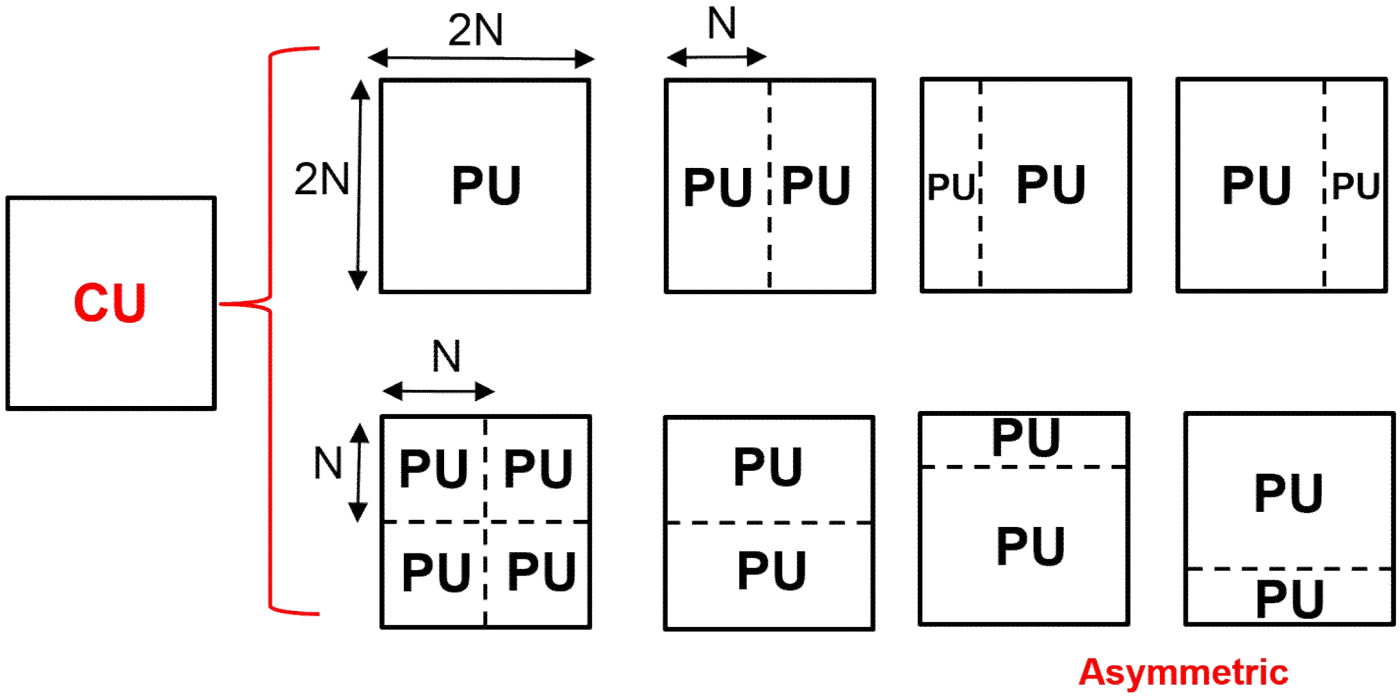
Coding Tree Unit and Coding Unit

- Coding Tree Unit (CTU) – basic processing unit, conceptually similar to macroblock in AVC/H.264
- Coding Unit (CU) – basic coding unit obtained by quadtree splitting of CTU



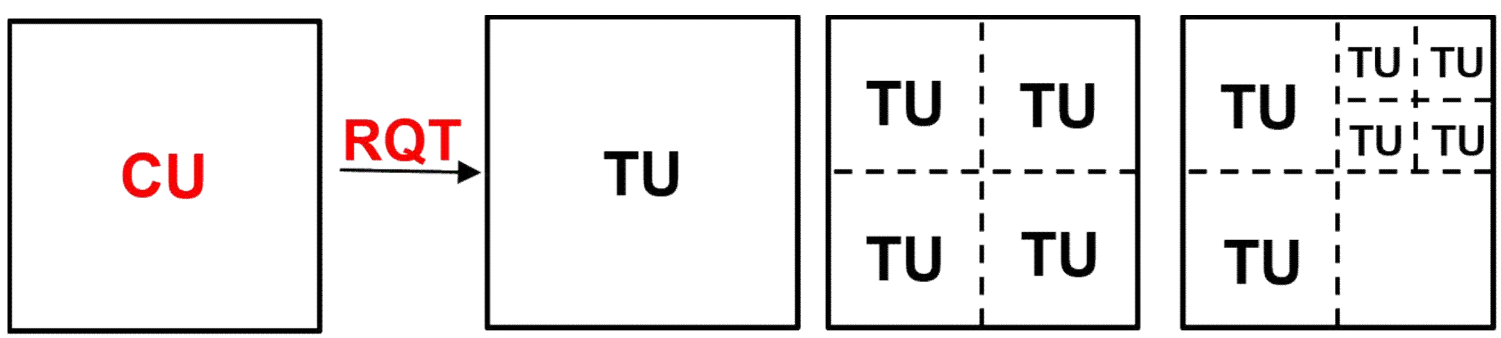
Prediction Unit (PU)

- Basic unit for inter- or intra-picture prediction, obtained by CU splitting
  - Intra prediction limited to 2Nx2N, NxN
  - NxN only at the smallest CU level (e.g. 8x8)



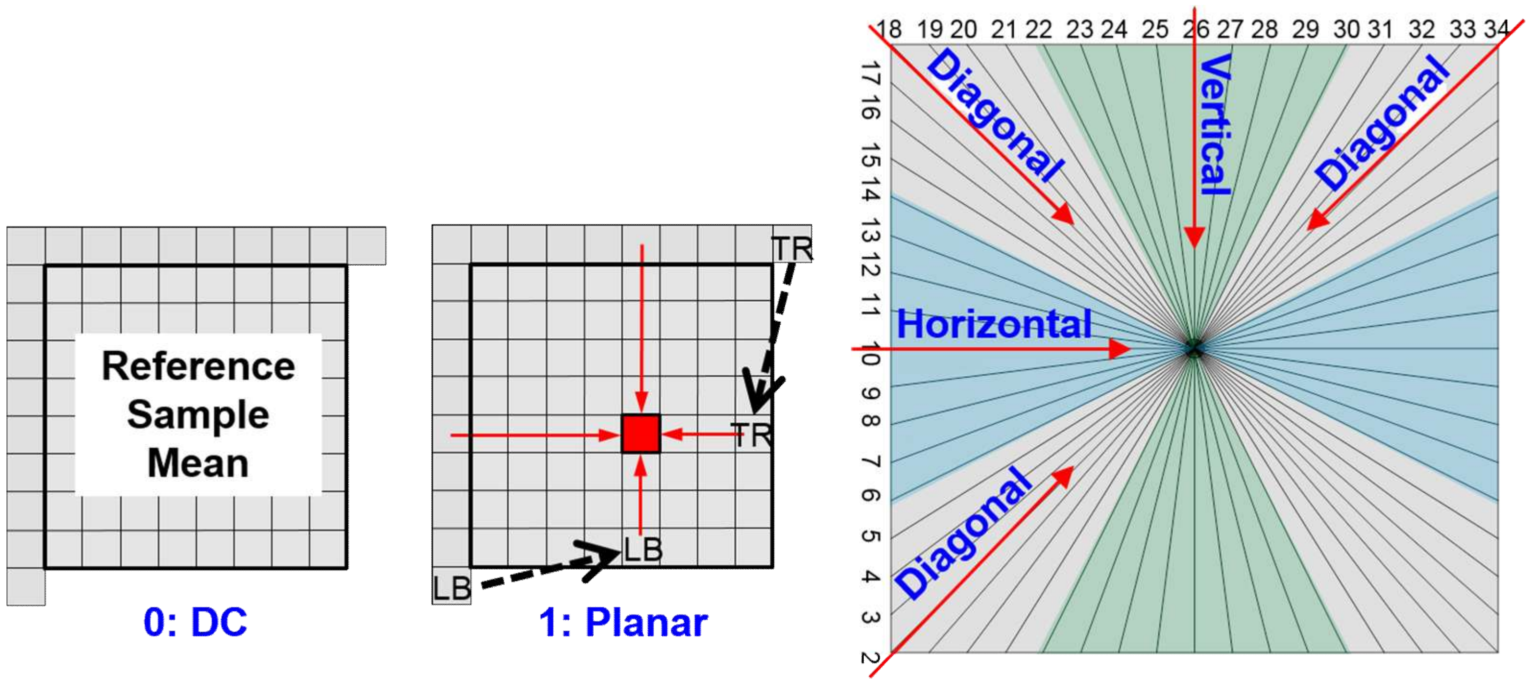
Transform Unit (TU)

- Basic unit for block transform of residuals, signaled by a residual quadtree
  - DCT-like transform (4x4 – 32x32)
  - DST-like transform for intra 4x4
  - TU can span across inter-predicted PUs



Intra Prediction

- Angular (9→33), Planar and DC predictions
  - PUs of size from 4x4 to 32x32
  - Adaptive reference sample filtering (1, 2, 1)
  - Boundary smoothing for DC/Hor./Ver. modes

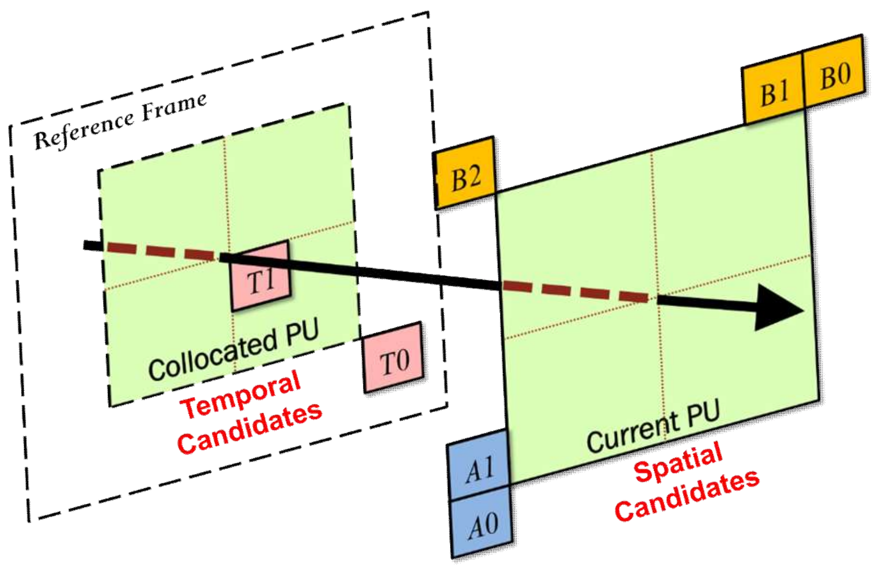


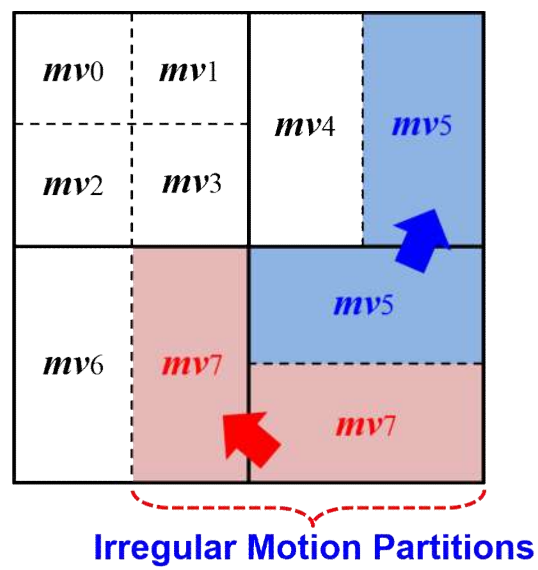
Inter Prediction

- Asymmetric motion partitioning
  - 2NxU, 2NxD, 2NxL, 2NxR
- DCT-based separable fractional-pel interpolation
  - 8-tap (−1, 4, −11, 40, 40, −11, 4, -1) for **half** samples
  - 7-tap (−1, 4, −10, 58, 17, −5, 1) for **quarter** samples
  - Less rounding operations
- Motion merging
- Adaptive motion vector prediction

Motion Merging

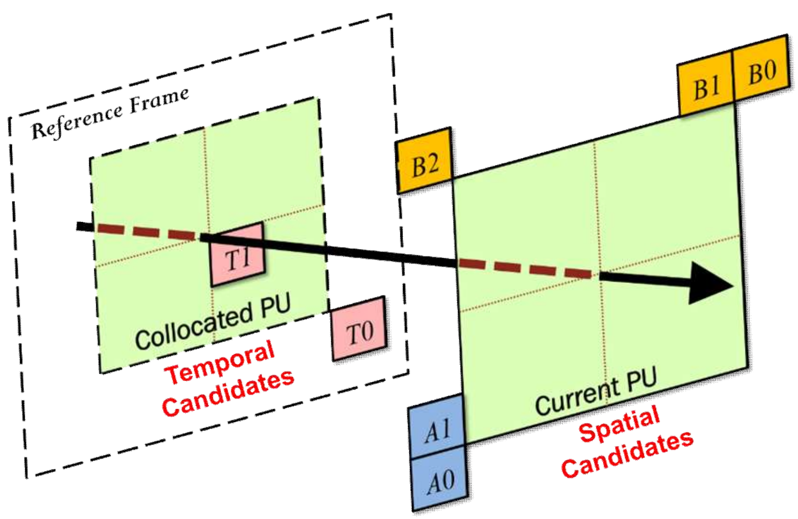
- Deriving motion from spatial and temporal neighbors
  - Spatial: (A1→B1→B0→A0→B2)
  - Temporal (<u>if enabled</u>): (T0→T1)
  - Generated (<u>if necessary</u>): synthesized from existing ones
- Special case: Merge skip

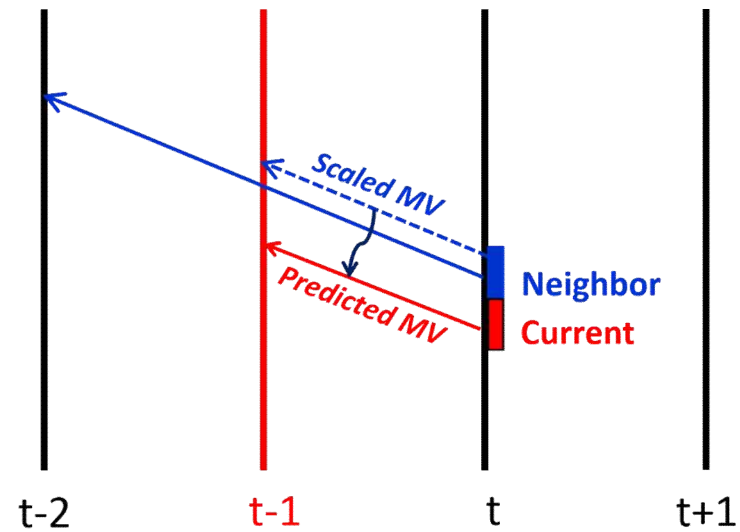




Adaptive Motion Vector Prediction

- Predicting MVs from spatial and temporal neighbors
- TWO predictors: (A0→A1) and (B0→B1→B2)
  - Temporal (if enabled and necessary)
  - Zero motion vector (if necessary)
- MV scaling may apply when necessary





Sample Adaptive Offset (SAO)

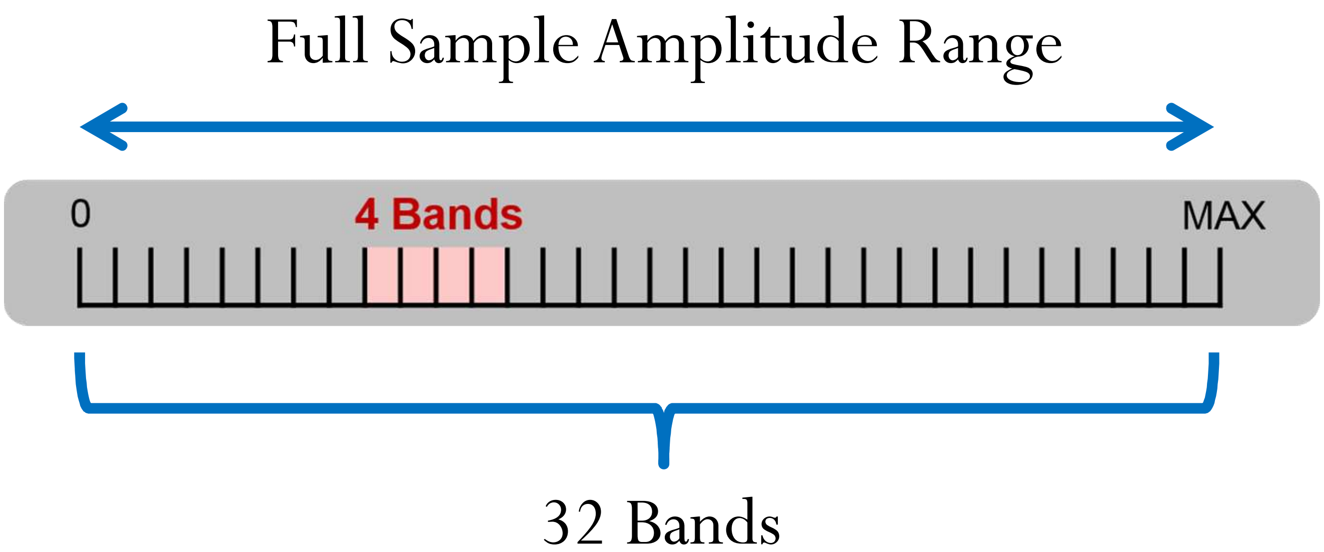
- To enhance visual quality both in flat areas and around edges by adding offset values to decoded samples after deblocking

1) **Classifying** samples on a CTU basis based on
- Sample value (Band Offset mode)
- Gradient pattern (Edge Offset mode)

2) **Modifying** samples in each category by adding a category-specific offset value

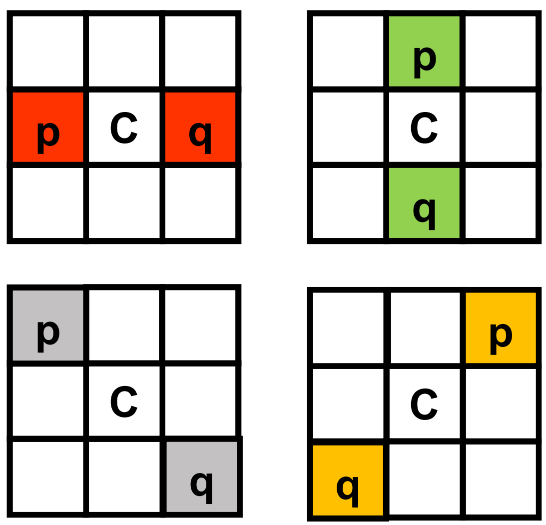
Band Offset Mode

- Uniform division of full amplitude into 32 bands
- Samples in 4 consecutive bands are modified

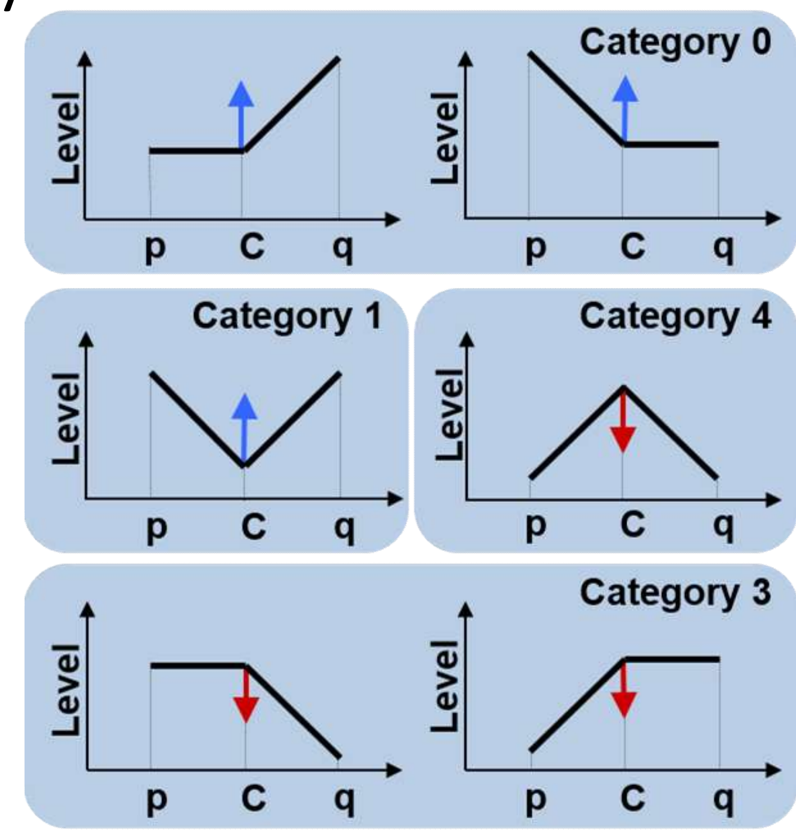


Edge Offset Mode

- Choosing one of the gradient patterns to apply
- Comparing sample C with two of its neighbors (p & q) to determine its category

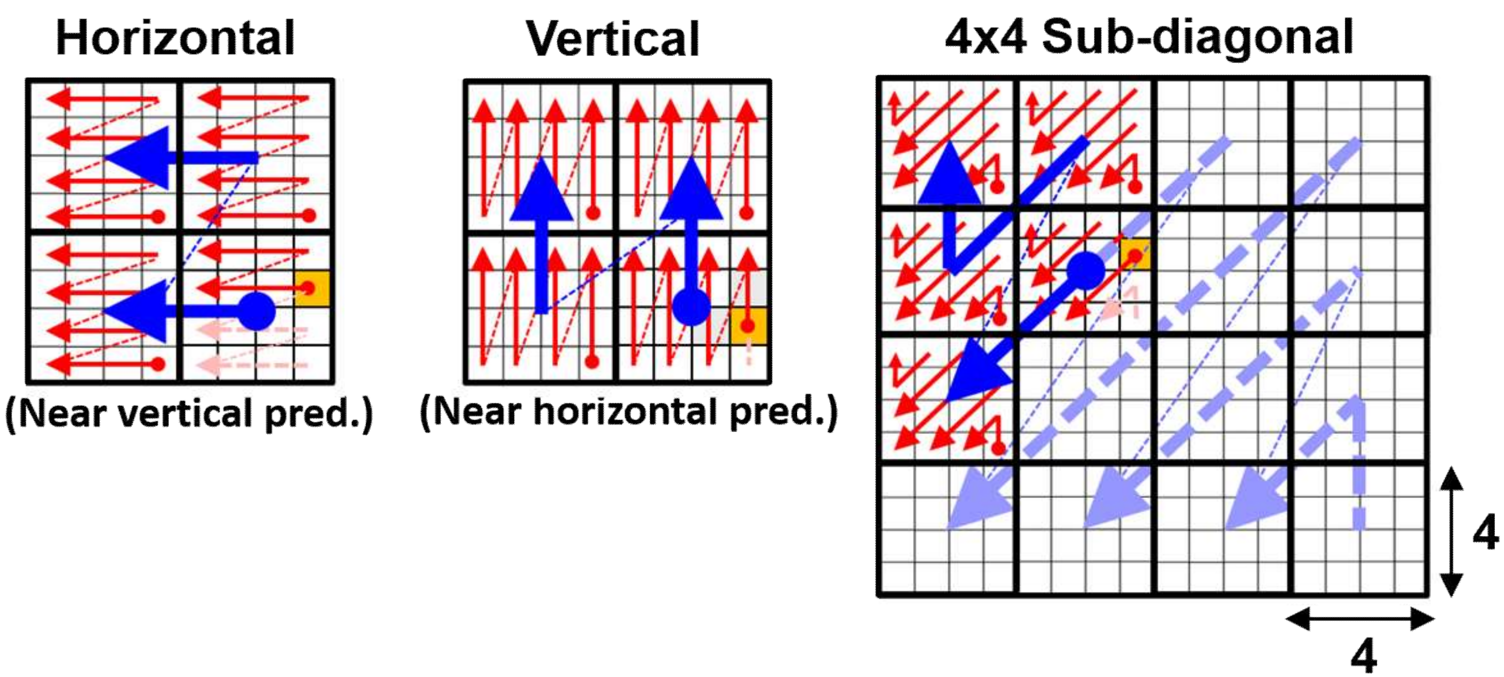


Gradient Patterns



Transform Coefficient Scanning

- Working on a 4x4 sub-block basis for all transform sizes with adaptive scanning
  - Intra 4x4, 8x8 – horizontal, vertical, diagonal
  - Others (Inter, Intra 16x16, 32x32) – diagonal

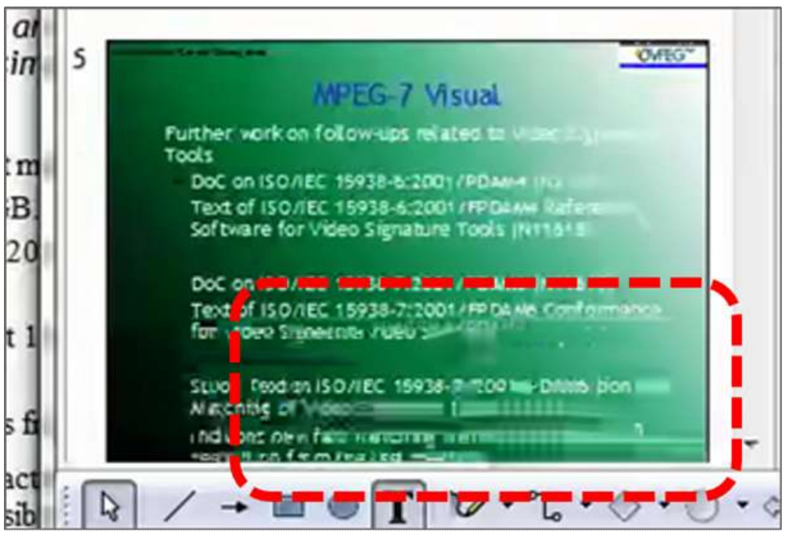


Transform Skip (TS)

- To improve coding of screen content by skipping transform adaptively for 4x4 TUs

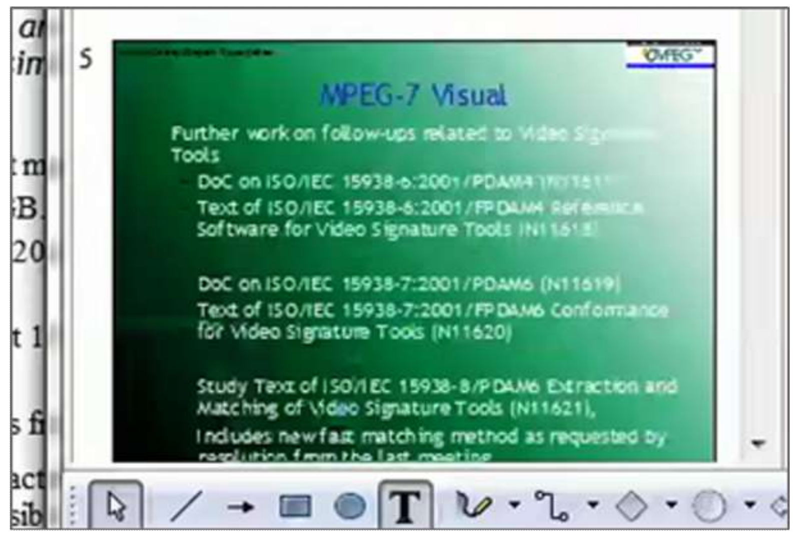
  → Quantization and entropy coding remain the same

TS Disabled



(QP37, 608.4Kbps, 34.8dB)

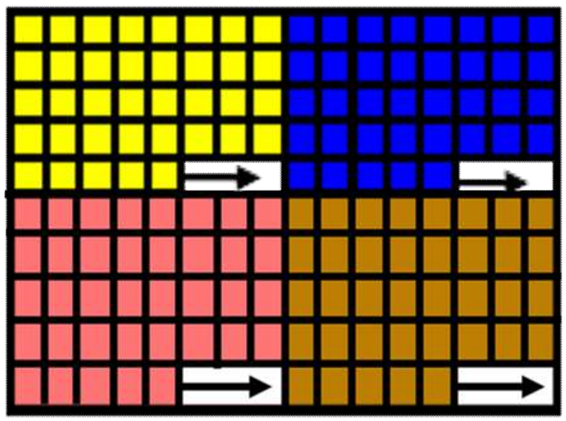
TS Enabled



(QP36, 600.8Kbps, 36.1dB)

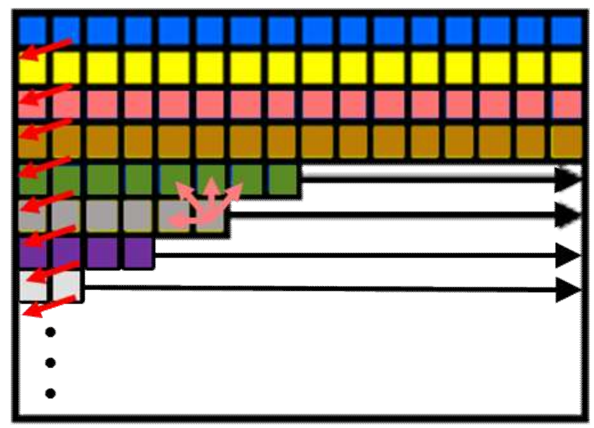
Parallel Processing

- **Tiles** – independently decodable regions



[4 Tiles in a Slice/Picture]

- **Wavefront** – parallel CTU rows processing



[n Waves in a Slice]

	Tiles	Wavefront
Parsing	Independent	Dependent
Reconstruction	Independent	Dependent
Granularity	Coarse (Regions)	Fine (CTU Rows)

Seeing is believing …

AVC/H.264

HEVC/H.265

Basketball Drive: 832x480_30Hz @ 1Mbps

Compression ratio ~144

Mass Adoption?

- Appeared on few devices and in trial services
- **Mass adoption has yet to occur** -- waiting for content providers to switch over

iPhone 6

Video Calling[3]

FaceTime video

Initiate video calls over Wi-Fi or cellular to any FaceTime-enabled device

FaceTime over cellular uses H.264/H.265

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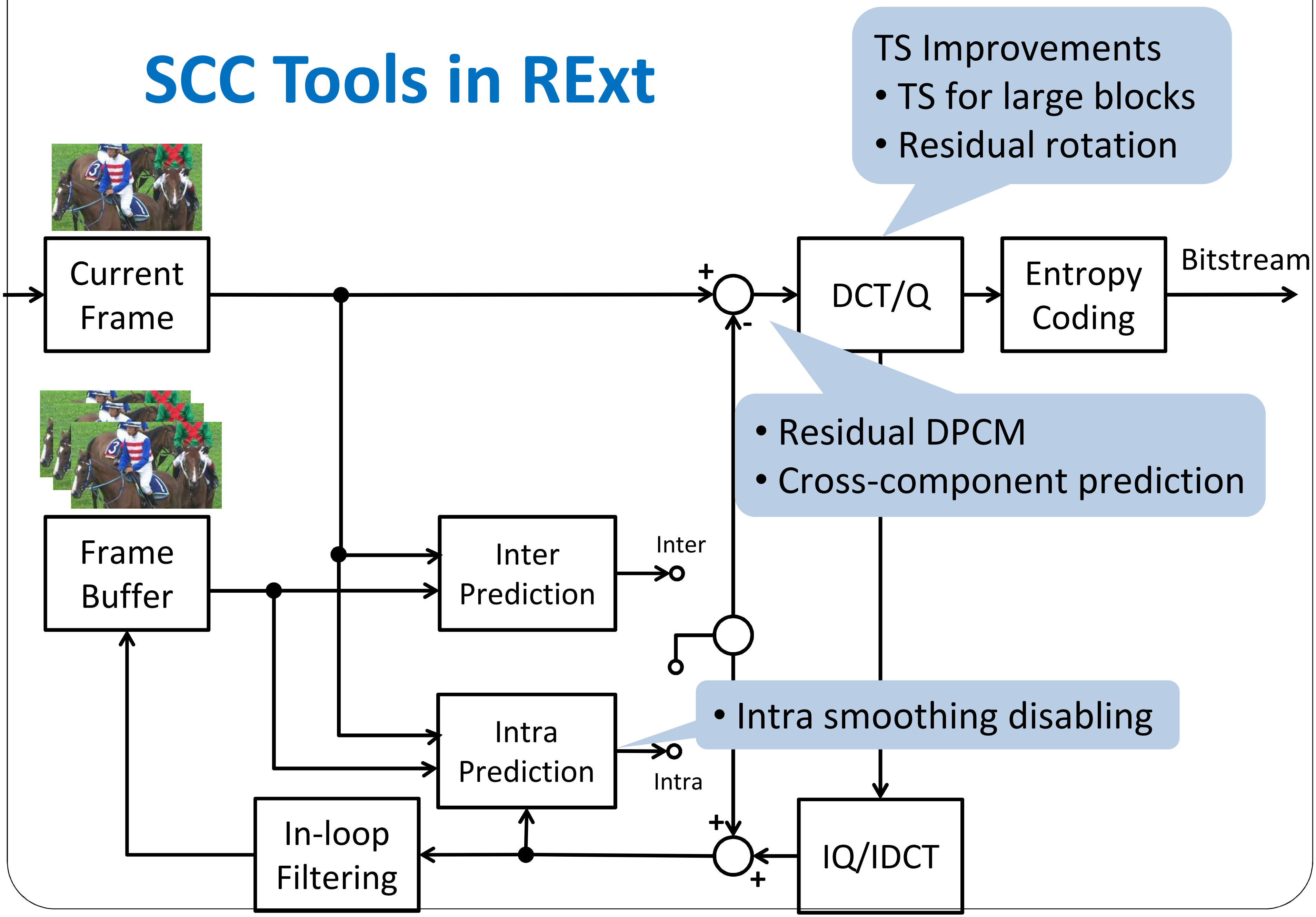
Range Extensions (RExt)

- **Objective:** Minimum changes to version 1 for added support of
  - Non-4:2:0 chroma formats
  - Higher bit depths (>10)
  - Improved lossless coding
  - Screen content coding (SCC)
- Tools beneficial to SCC only were removed due to the creation of SCC Extensions

Tool Features in RExt

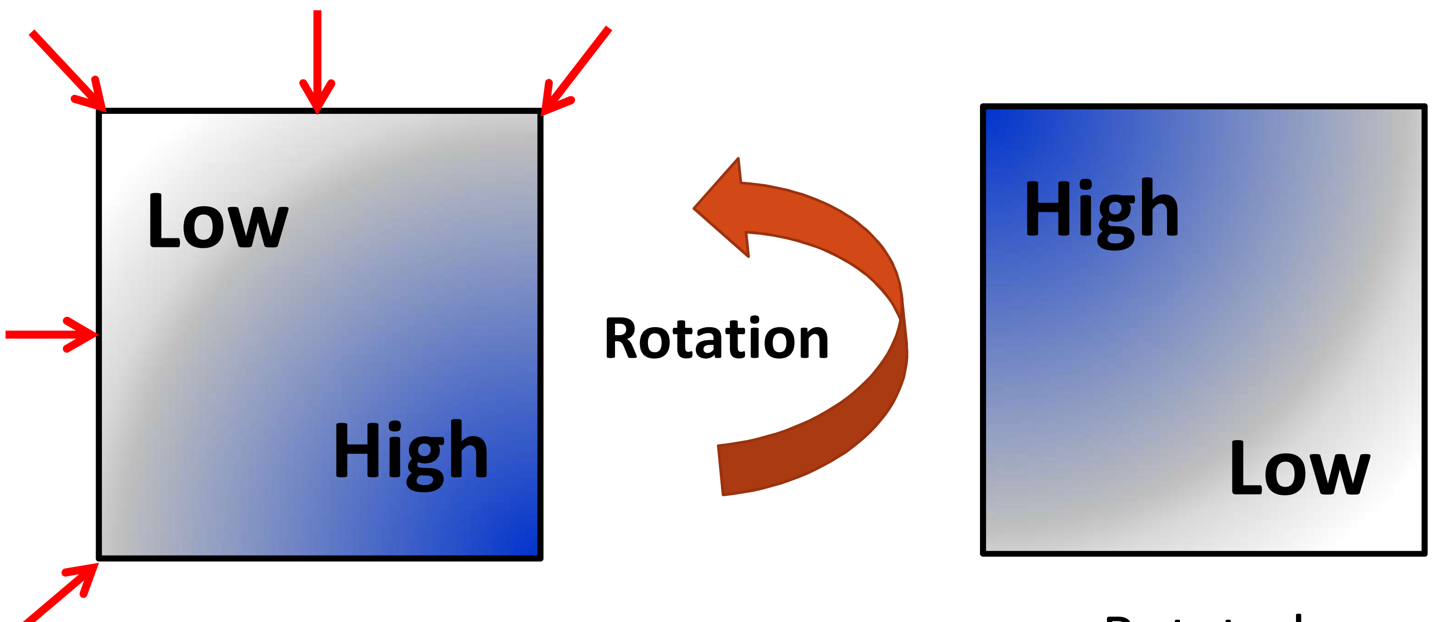
- **Transform skip improvements**
- **Residual DPCM (Implicit/Explicit)**
- **Cross-component prediction**
- **Intra smoothing disabling**
- Golomb-rice parameter adaptation
- CU-adaptive chroma QP offset
- CABAC bit alignment
- High precision interpolation, prediction, and transform

SCC Tools in RExt



Transform Skip (TS) Improvements

- Enable TS for any block size (4x4 only in v1)
- Rotate 4x4 intra TS residual blocks by 180 degree
- Single CABAC model for significance map coding

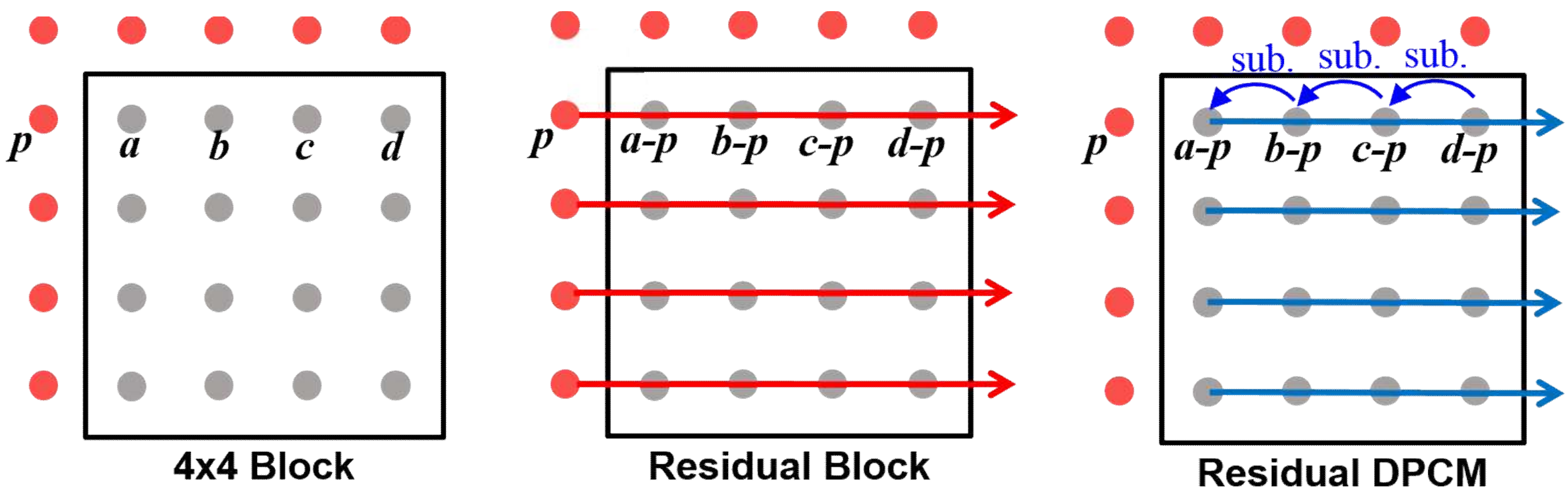


Energy Distribution
(Intra 4x4 TS)

Rotated
Residual Block

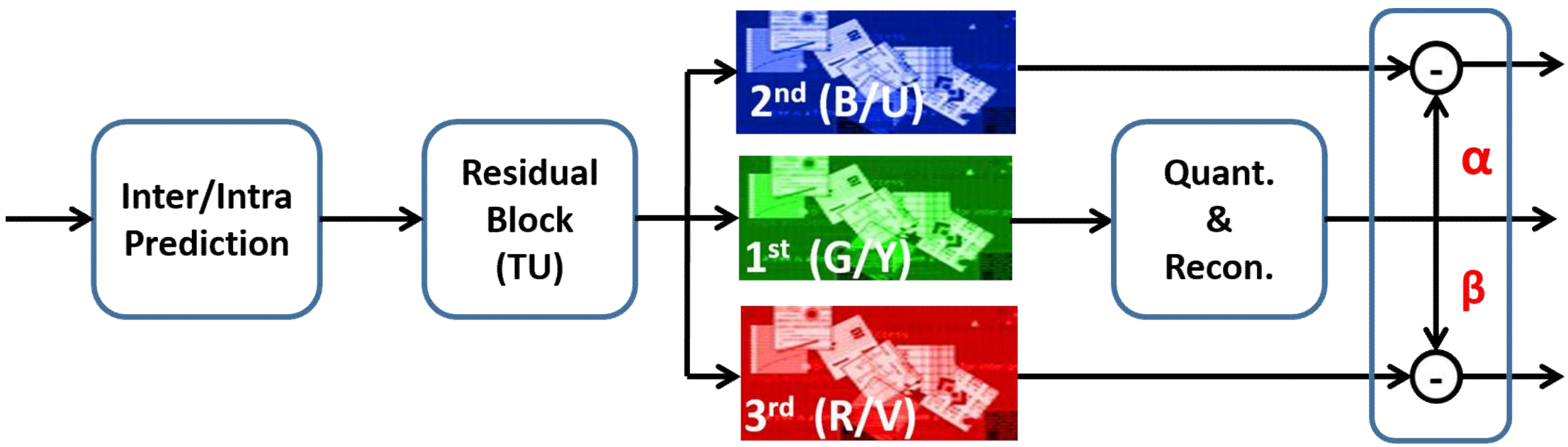
Residual DPCM

- Enable horizontal/vertical prediction of residual signals in TS blocks -- **Short-distance Prediction**
- **Implicit** (explicit) direction signaling for **Intra** (Inter)



Cross-component Prediction (CCP)

- Predict the residual of the 2nd and 3rd color components from that of the 1st with weighting
- Applicable to all color formats (e.g. RGB and YUV)

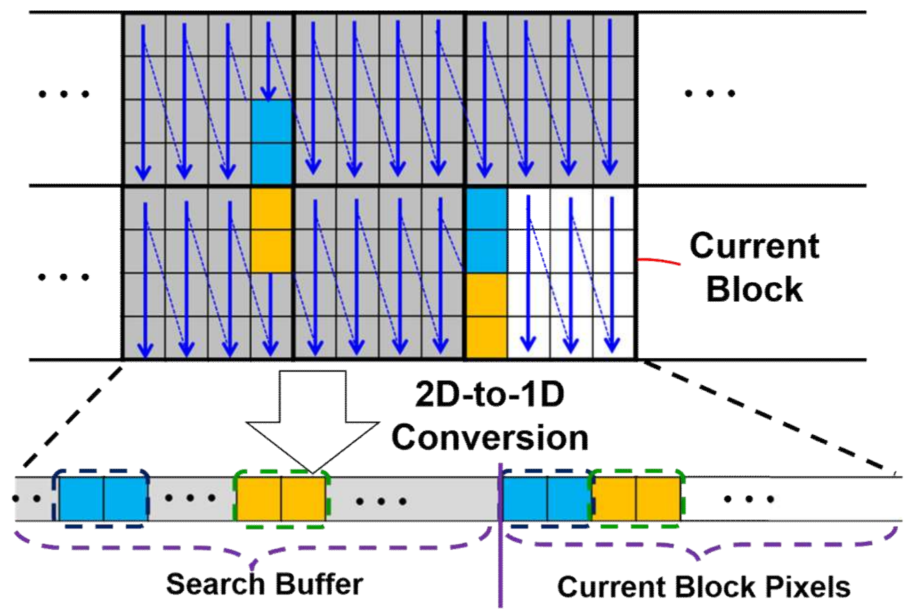


$\alpha, \beta \in (\pm 8, \pm 4, \pm 2, \pm 1, 0)/8$

Other Tools: Pseudo 2-D Matching (P2M)

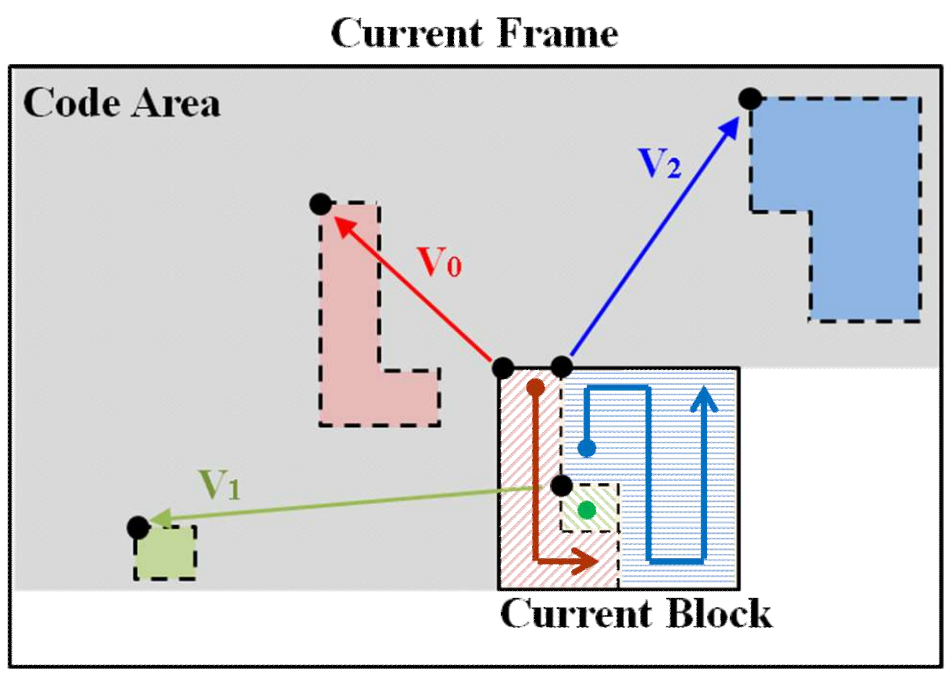
- Applying **string matching** to image coding
  1) Scanning 2-D image into 1-D signal
  2) Indicating the longest matching string with (pointer, length)

Same principle as LZ coding for data compression!!



Other Tools: Intra String Copy (ISC)

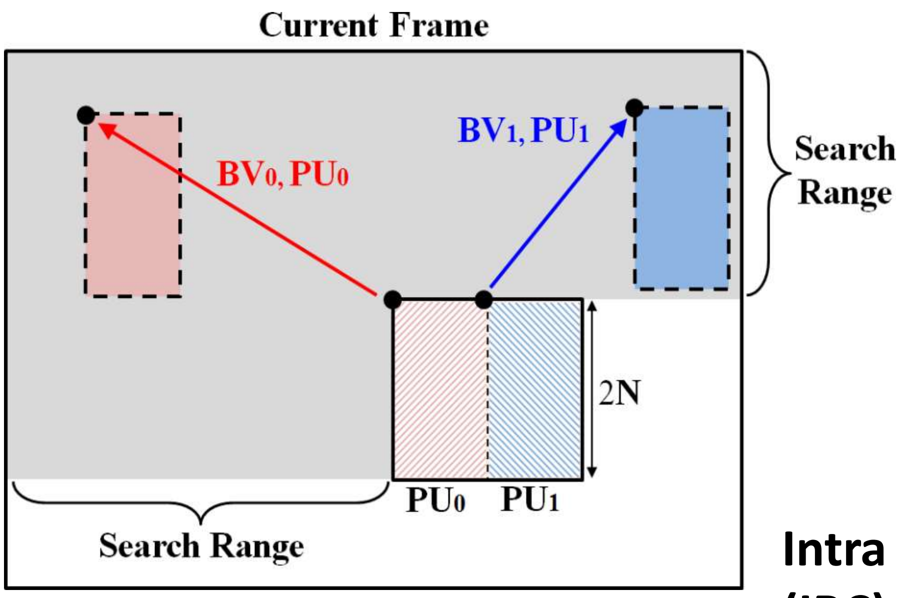
- 2-D matching to preserve image structure
- Effective for addressing **repetitive patterns**
- **Cons:** 1) sequential operation; 2) irregularity

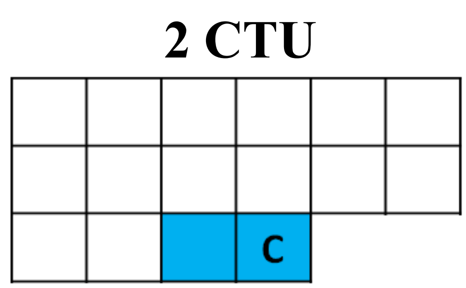


Intra String Copy (ISC)

Other Tools: Intra Block Copy (IBC)

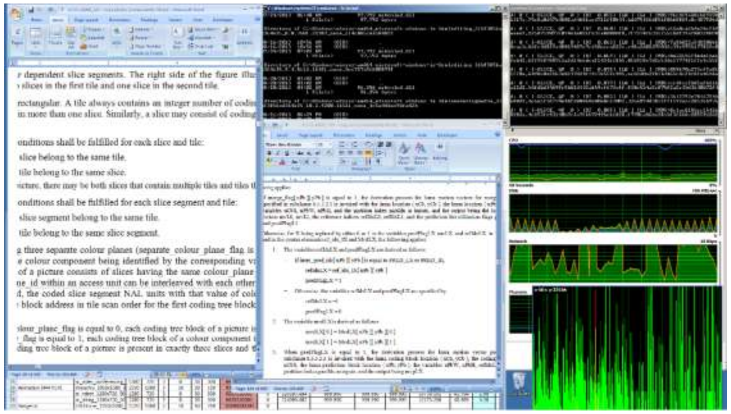
- **Idea:** Copying blocks from the decoded region (w/o deblocking) within the same picture
- Operation similar to motion compensation
- Substantial gains (>30%) with 2-CTU search





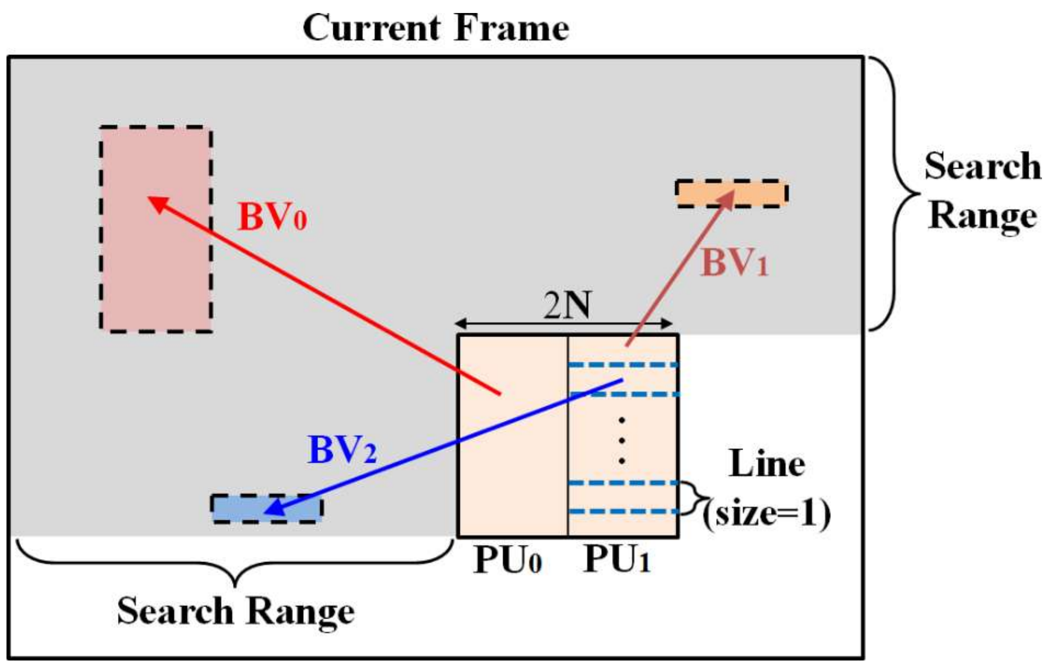
Intra Block Copy (IBC)

IBC tends to work more effectively with small block sizes and non-square partitions



Other Tools: Intra Line Copy (ILC)

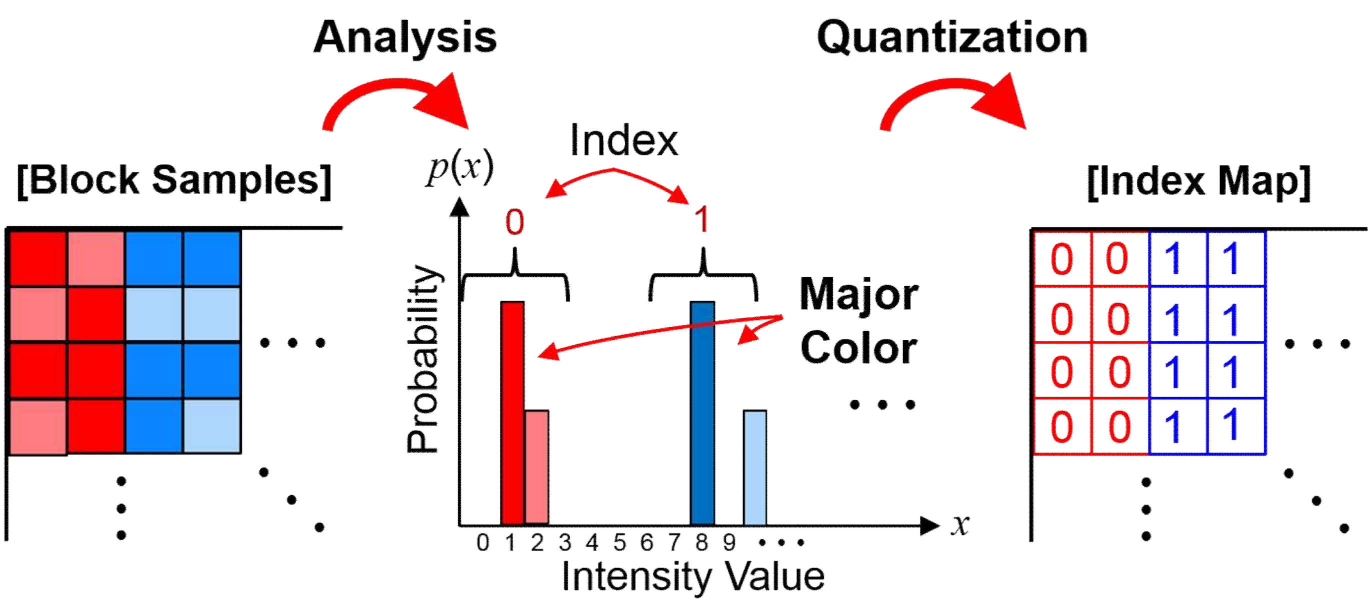
- Finer granularity for sample copying
- Line – 1x4/4x1, 1x8/8x1, 1x16/16x1
- 7-10% gains on top of IBC (similar to ISC)



Intra Line Copy (ILC)

Other Tools: Palette Mode

- Representing pixels in a coding block with few **major color** values using **palette indices**
- Effective for coding signals in **discrete-tone areas**
- 10-15% gains on top of IBC



Behind Stories

- Intra Block Copy (IBC)
  - Gains (>30%) only seen on screen content
  - Considerable increase in complexity
  - Promising results from SCC Call-for-Proposals

  → To consider IBC in the context of SCC Extensions
- Palette Mode
  - Decent gains (>10-15%)
  - Technologies not converging yet
- Intra String/Line Copy (ISC & ILC)
  - Low hanging fruit first