DRASTIC: Dynamically Reconfigurable Architecture Systems for Time-varying Image Constraints

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Acknowledgment
This material is based upon work supported by the National Science Foundation under NSF AWD CNS1422031.

Talk Outline

- Motivation
- Related work
- Video communication examples
- Video analysis examples
- Discrete Periodic Radon Transform (DPRT)
- Conclusion

Motivation: Video Compression

HDTV video bandwidth requirements:

- Has interlaced and progressive modes.
- 720p: progressive, 1280x720 pixels, 60 frames per second.
  Raw BW (24 bits/pixel): ***1.3Gbps***
- 1080i: interlaced encoding, 1920x1080 pixels, 25 frames per second.
  Raw BW (24 bits/pixel): ***1.2Gbps***
- 1080p: progressive, 1920x1080 pixels, 59.94 frames per second.
  Raw BW (24 bits/pixel): ***2.98Gbps***

Ultra High Definition (hypothetical framerates):

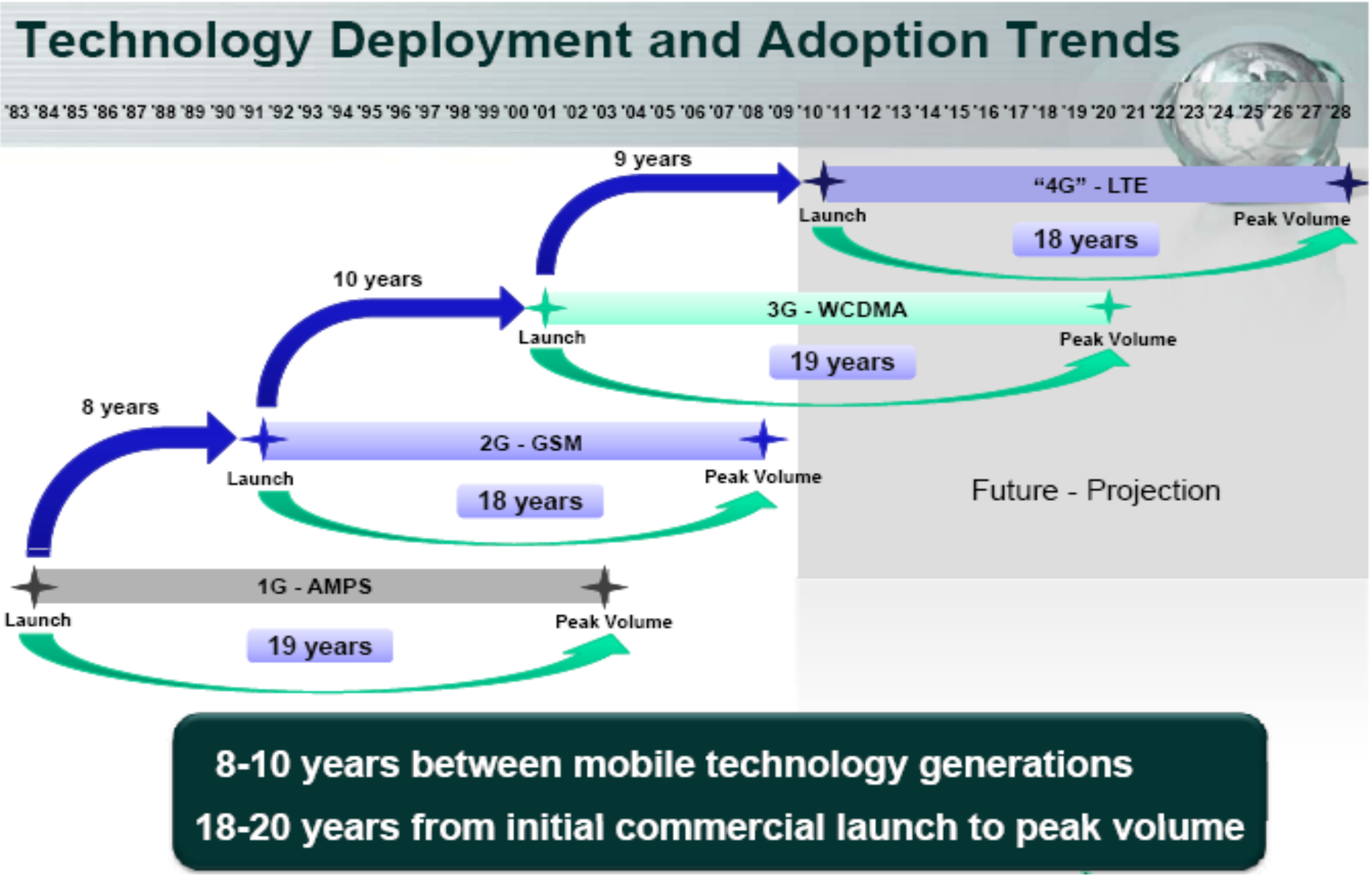
- 4K UHD: 3840x2160 (2160p 16:9): 24 bits/pixel@30 fps: ***5.56Gbps***,
  4096x2048 (4K x 2K), 4096x2160 (1.9:1), 4096x2304 (16:9),
  4096x3072: 24 bits/pixel @120 fps: ***33.75Gbps.***
- 8K UHD: 7680x4320 (4320p): 24 bits/pixel@30 fps: ***22.24Gbps***
  8192x4096, 8192x4320: 24 bits/pixel@120 fps: ***94.92Gbps***

Mobile Comm. Networks Data Transfer Rates

Type	Theoretical Transfer Rates	Typical Transfer Rates
2G- GSM (early 1990s)	9.6 – 115 kbps	About 10 kbps
2.5G-GPRS (2001)	9.6 - 171.2 kbps	Between 30-50 kbps
2.5G- EDGE (2003)	9.6 -384 kbps	Between 75-135 kbps
3G- UMTS (2001)	144 kbps - 2 Mbps	Between 220-384 kbps
3.5G-HSPA (Rel. 7) (HSDPA , Rel. 5, 2005) (HSUPA, Rel. 6, 2008)	DL: 14Mbps UL: 5.8 Mbps	DL : 1-4 Mbps UL : 500Kbps -2Mbps
3.5G- Mobile WiMAX (IEEE 802.16e, 2005)	DL: 46 Mbps UL: 5.6 Mbps	As for 3.5-HSPA
4G-LTE-Advanced (Rel. 10, Oct. 2010)	DL: 1Gbps UL: 100 Mbps	N/A: See below
4G- WirelessMAN-Advanced (IEEE 802.16m, Oct. 2010)	DL: 1Gbps UL: 100 Mbps	N/A: See below

Refer to slides 159-188 from “4G …” from http://www.4gamericas.org/

Mobile Communication Networks Evolution



8-10 years between mobile technology generations

18-20 years from initial commercial launch to peak volume

Video Compression Rates

3G UMTS (2001) max typical = **384 kbps**

- HDTV 720p: **1.3Gbps / 384 kbps = 3,549**
- UHD 8192x4320 (hyp): **94.92Gbps / 384 kbps = 251,058**

4G-LTE-Advanced @ max theoretical upload = **100 Mbps**

- HDTV 720p: **1.3Gbps / 100 Mbps = 13.3**
- UHD 8192x4320 (hyp): **94.92Gbps / 100 Mbps = 972**

CR for HEVC Studies using ultrasound videos:
720x576(4CIF) (8 bits/pixel-yuv420@25fps) = **81.1 Mbps**
HEVC encoding using QP 36 and x265 ultra-fast profile:
PSNR: 32dB, 364 kbps, compression ratio = **223**

Still Image Criteria for Medical Video

	Plaque Motion	Stenosis	Plaque Morphology
5	plaque(s) motion(s) in transmitted video identifiable as in original	degree of stenosis in transmitted video determined as in original	plaque morphology in transmitted video is the same as in original
4	plaque(s) motion(s) in transmitted video has artefacts that do not compromise diagnosis	enough clinical data to determine degree of stenosis	Some artefacts are seen that do not compromise morphology visualization
3	plaque(s) motion(s) artefacts that can compromise diagnosis	clinical data only allow approximation of degree of stenosis	Artefacts may compromise morphology visualization
2	plaque(s) motion(s) artefacts that significantly limit diagnosis	very limited ability to estimate degree of stenosis	Significantly limit diagnosis
1	Not visible	not determinable	Not visible.

Assessed by humans for atherosclerotic plaque ultrasound.

Motivation: Multi-objective Opt

Provide Constraints for better control on Image and Video Compression

Power

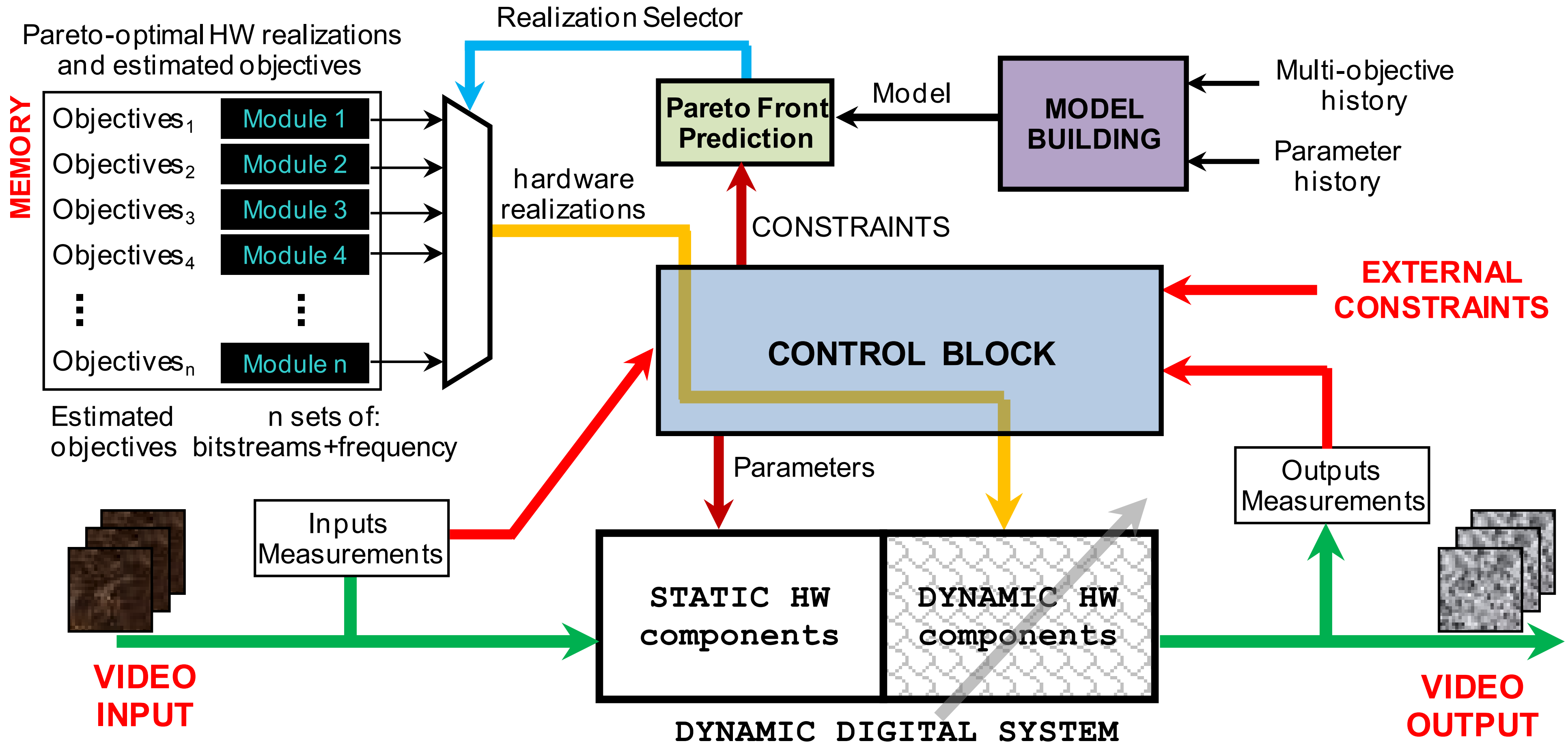
Bitrate

Quality

Motivation: Multi-obj (more)

- Adaptive accuracy based on changes in the video
- Real-time video communications performance
- Fast image processing with limited computational resources (e.g., scalable DPRT)
- Large datasets with limited resources

Video Processing System



Pareto-optimal HW realizations and estimated objectives

Realization Selector

MEMORY

Objectives$_1$ Module 1

Objectives$_2$ Module 2

Objectives$_3$ Module 3

Objectives$_4$ Module 4

⋮ ⋮

Objectives$_n$ Module n

Estimated objectives

n sets of: bitstreams+frequency

hardware realizations

Pareto Front Prediction

Model

MODEL BUILDING

Multi-objective history

Parameter history

CONSTRAINTS

EXTERNAL CONSTRAINTS

CONTROL BLOCK

Parameters

Inputs Measurements

Outputs Measurements

STATIC HW components

DYNAMIC HW components

DYNAMIC DIGITAL SYSTEM

VIDEO INPUT

VIDEO OUTPUT

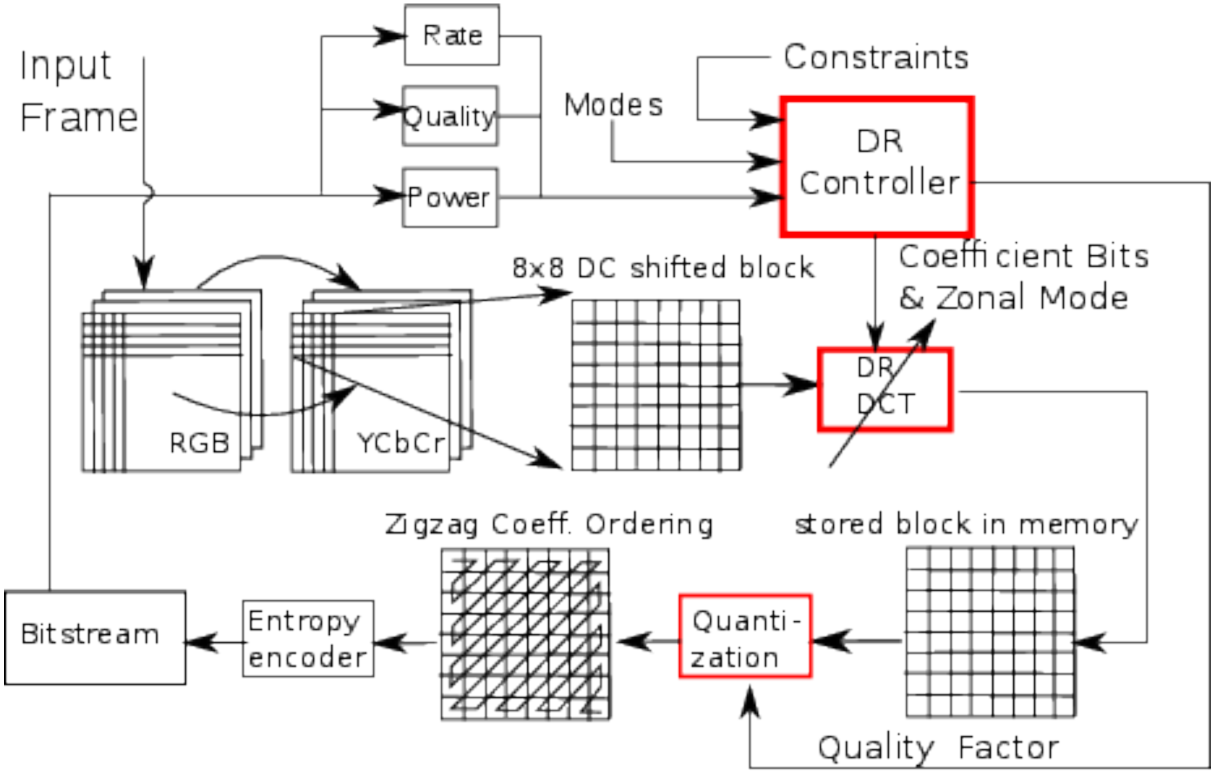
Modes for Video Comm.

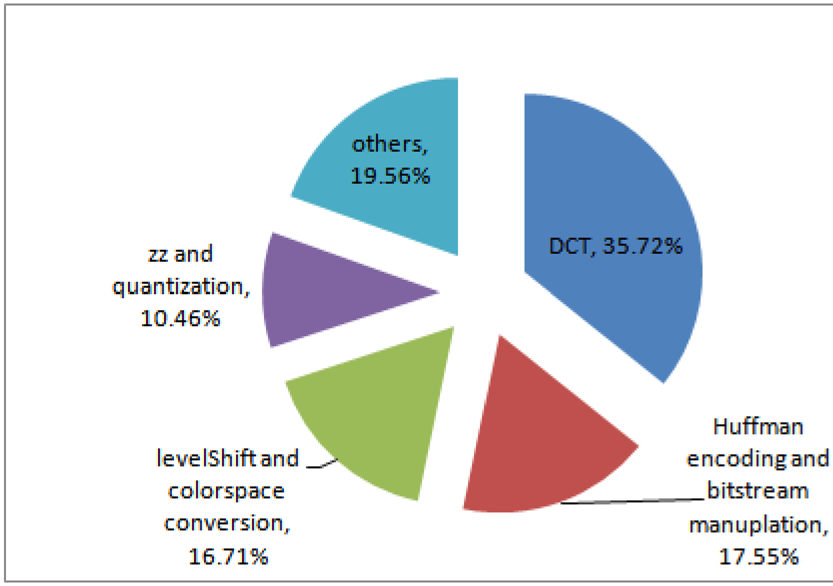
Mode	**Constraint Optimization Formulation**
Max Im. Qual.:	max $\mathtt{Q}$ subj. to: $(\mathtt{BPS} \leq \mathtt{B}_{\mathtt{max}})$ & $(\mathtt{DP} \leq \mathtt{DP}_{\mathtt{max}})$
Min Bitrate:	min $\mathtt{BPS}$ subj. to: $(\mathtt{Q} \geq \mathtt{Q}_{\mathtt{min}})$ & $(\mathtt{DP} \leq \mathtt{DP}_{\mathtt{max}})$
Min Dyn. Power:	min $\mathtt{DP}$ subj. to: $(\mathtt{BPS} \leq \mathtt{B}_{\mathtt{max}})$ & $(\mathtt{Q} \geq \mathtt{Q}_{\mathtt{min}})$
Typical Mode:	max $\alpha \cdot \mathtt{Q} - \beta \cdot \mathtt{BPS} - \gamma \cdot \mathtt{DP}$
	subj. to: $(\mathtt{Q} \geq \mathtt{Q}_{\mathtt{min}})$ & $(\mathtt{DP} \leq \mathtt{DP}_{\mathtt{max}})$ & $(\mathtt{BPS} \leq \mathtt{BPS}_{\mathtt{max}})$

We have the following objectives and bounds:

$\mathtt{DP}$	Dynamic Power, max avail.$=\mathtt{DP}_{\mathtt{max}}$
$\mathtt{Q}$	Image Quality, min. acceptable$=\mathtt{Q}_{\mathtt{min}}$
$\mathtt{BPS}$	Bits Per Sample, max avail.$=\mathtt{BPS}_{\mathtt{max}}$

DRASTIC DCT: System

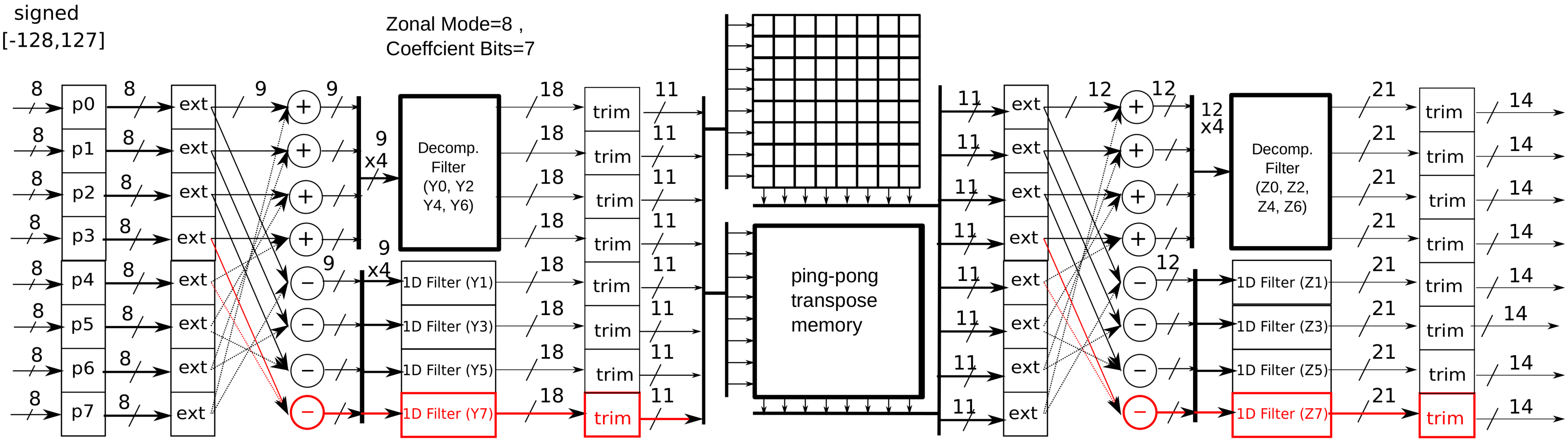




We have software/hardware control implementing DRASTIC modes using:

- SW: Adjustable Quantization Table (QF only)
- HW: Variable Zonal Coding
- HW: Adjustable Bitwidth of the DCT coefficients

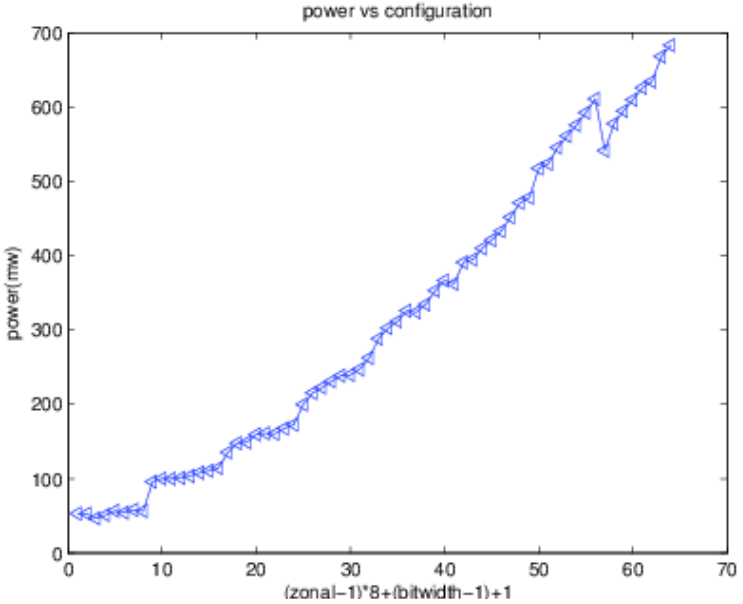
DRASTIC DCT: DCT HW

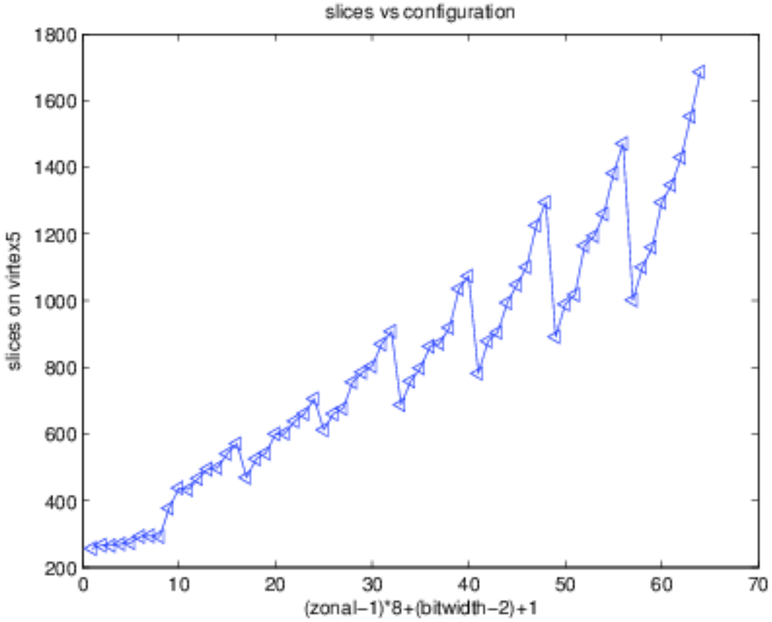


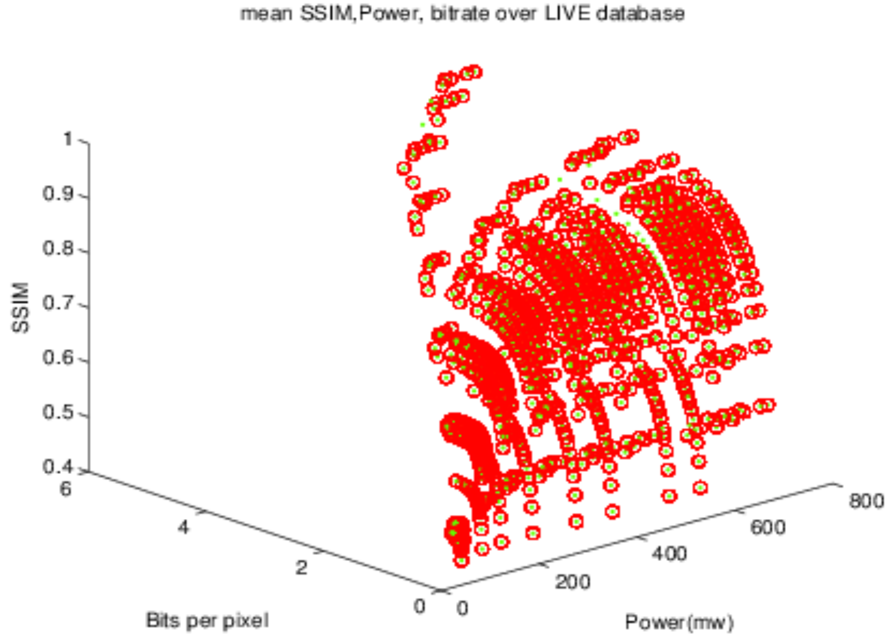
Variable Zonal Coding:

- Fine control providing 8 configurations
- Output will be extended to 16 bits
- Full implementation shown here: Removal of red-highlighted regions for implementing zonal=7 hardware mode.

DRASTIC DCT: Pareto Front







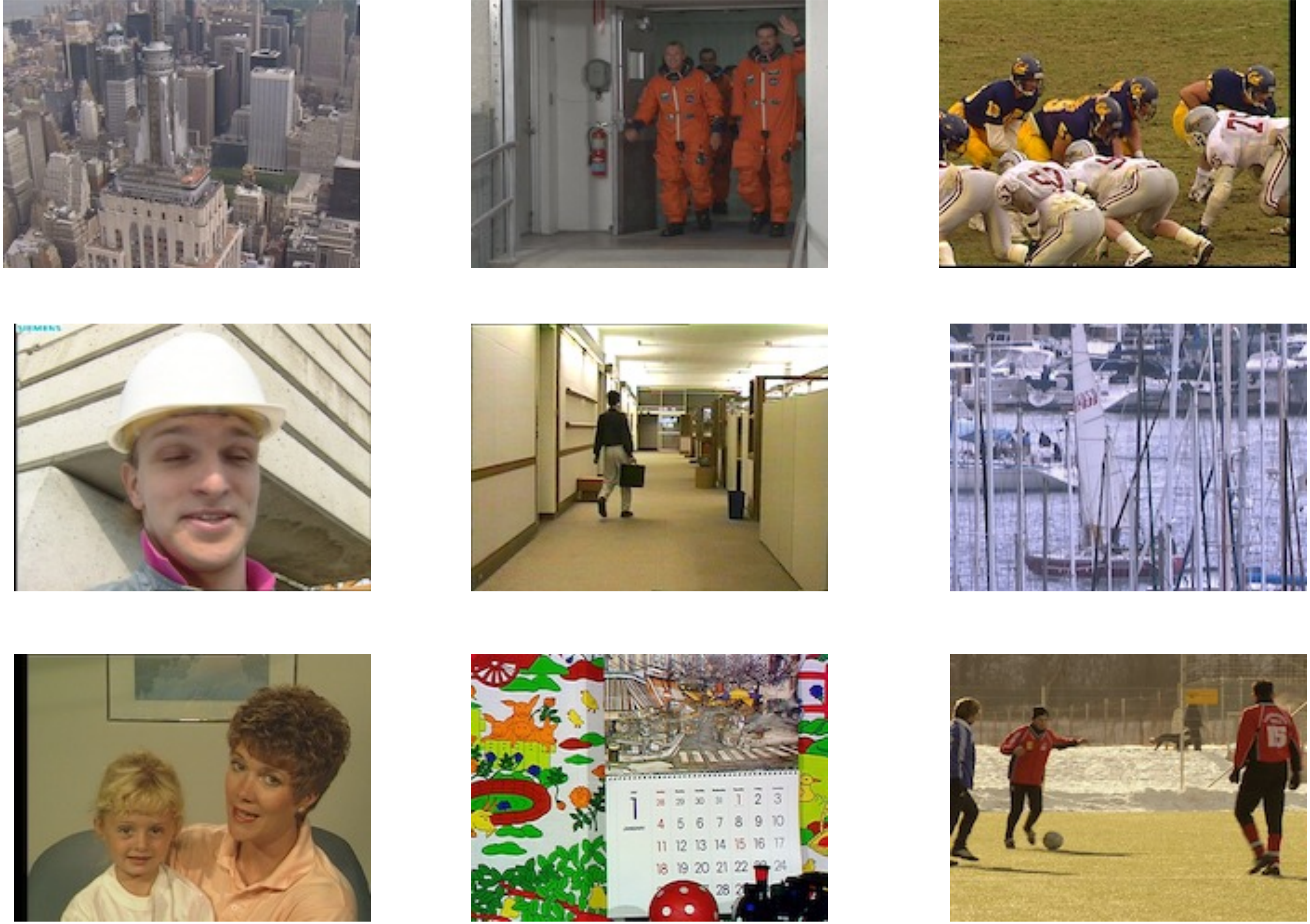
- QF: 5:5:100
- Zonal: 1:1:8
- Bitwidth: 2:1:9

Configurations = 1280

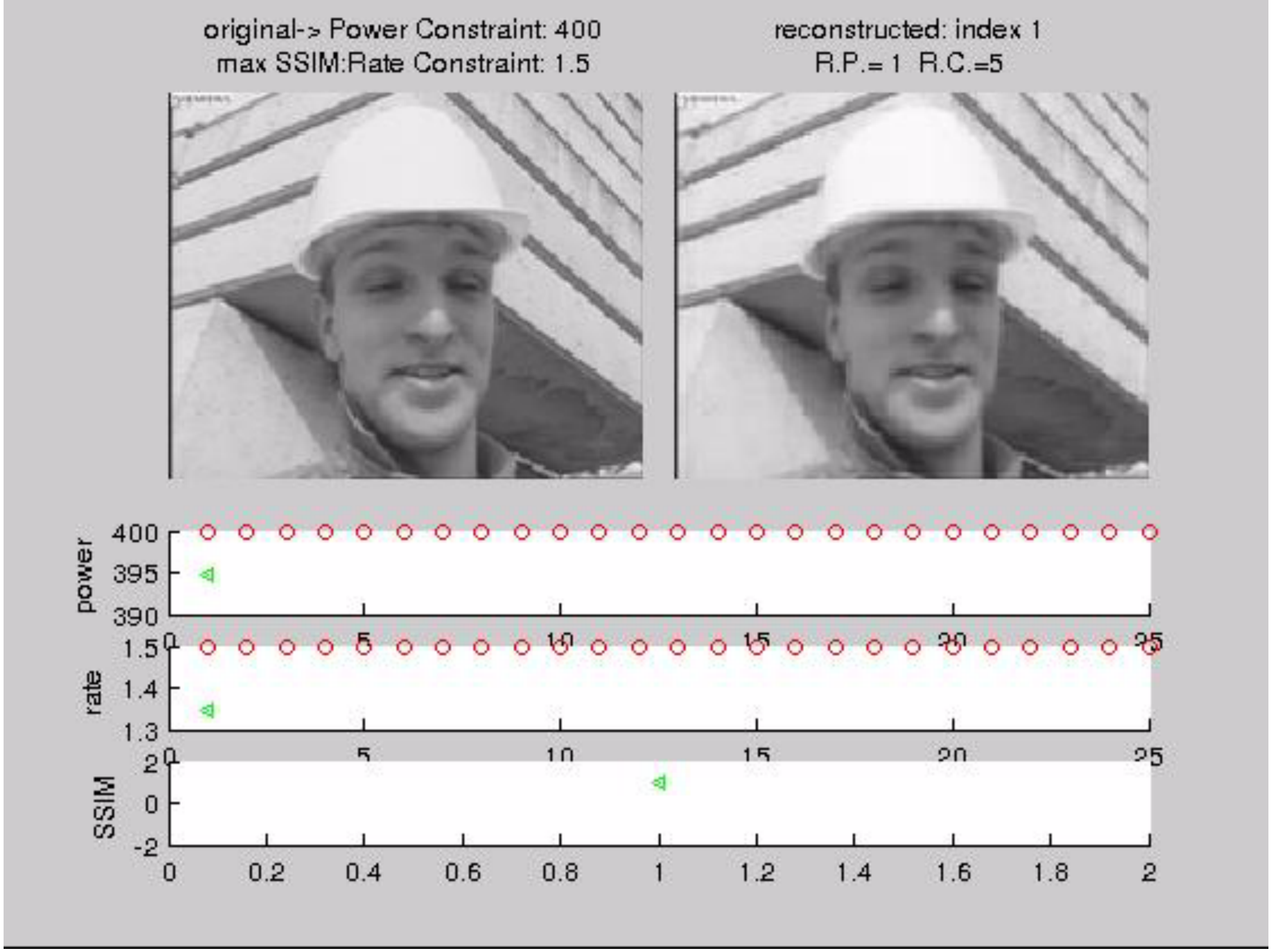
Pareto Optimal = 841

Pareto-optimal Configuration shown in red.
(based on median results over LIVE image database)

DRASTIC DCT: Image Database



DRASTIC DCT: Mode Transition



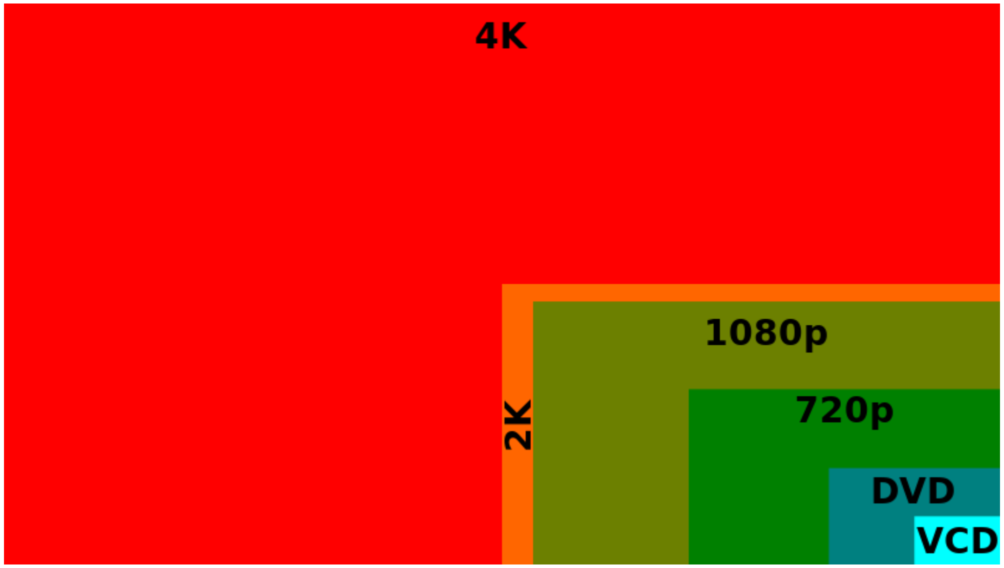
Ongoing Work: HEVC

The video coding standard H.264/AVC is the project HEVC started from. H.264/AVC is initially developed during 1999-2003, and was further extended in scalable video coding (SVC) and multi-view video coding (MVC) during 2003-2009.

Formal joint Call for Proposals (CfP) on HEVC started by VCEG mand MPEG was issued in January 2010.

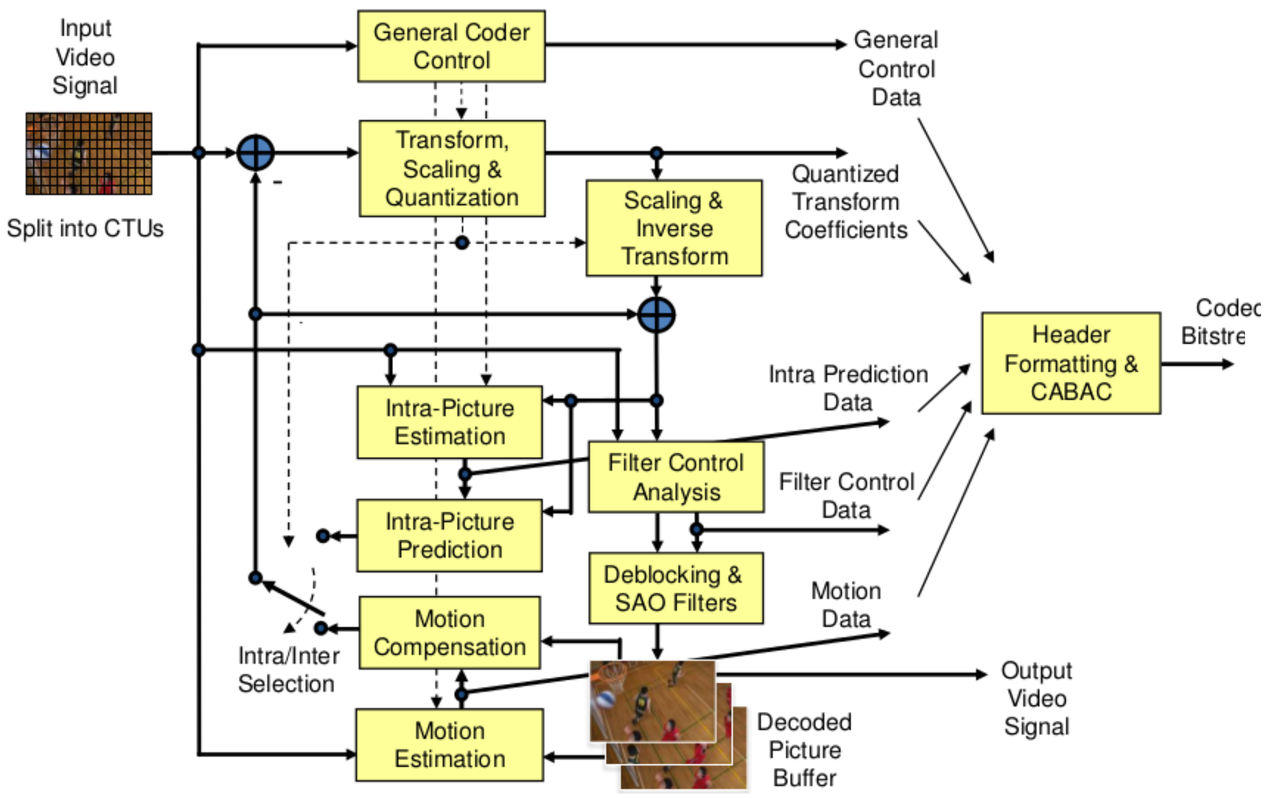
Motivation:

8K-UHD	(8192 × 4320)
4K	(4096 x 3072)



4. Ongoing Work: Intra-Prediction

THE UNIVERSITY of NEW MEXICO



Input Video Signal

Split into CTUs

General Coder Control

General Control Data

Transform, Scaling & Quantization

Quantized Transform Coefficients

Scaling & Inverse Transform

Header Formatting & CABAC

Codec Bitstre

Intra-Picture Estimation

Intra Prediction Data

Filter Control Analysis

Filter Control Data

Intra-Picture Prediction

Deblocking & SAO Filters

Motion Data

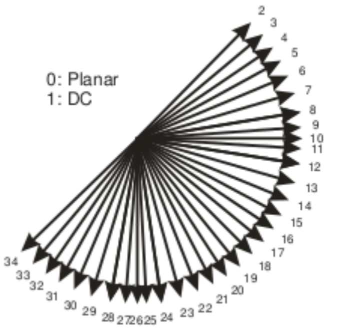
Motion Compensation

Intra/Inter Selection

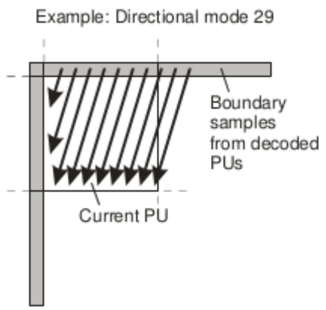
Output Video Signal

Motion Estimation

Decoded Picture Buffer



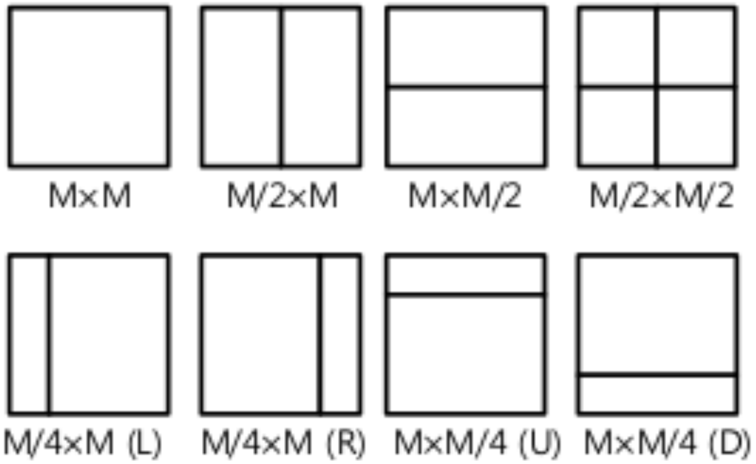
0: Planar
1: DC

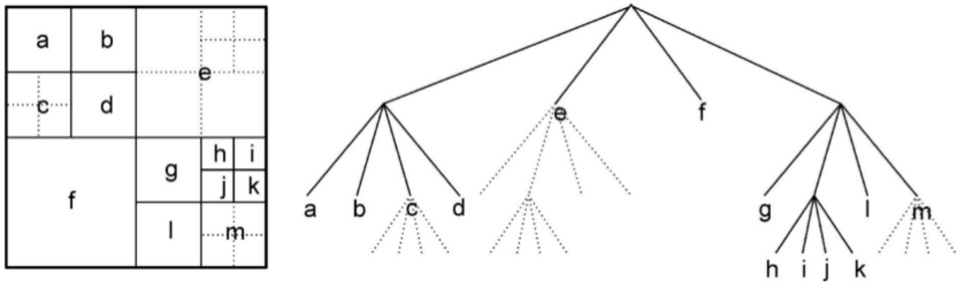


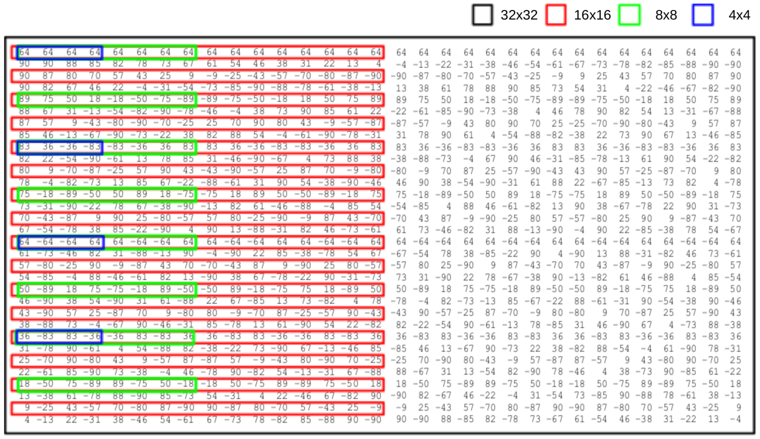
Example: Directional mode 29

Boundary samples from decoded PUs

Current PU







☐ 32x32 ☐ 16x16 ☐ 8x8 ☐ 4x4

64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64
90	90	88	85	82	78	73	67	61	54	46	38	31	22	13	4	-4	-13	-22	-31	-38	-46	-54	-61	-67	-73	-78	-82	-85	-88	-90	-90
90	87	80	70	57	43	25	9	-9	-25	-43	-57	-70	-80	-87	-90	-90	-87	-80	-70	-57	-43	-25	-9	9	25	43	57	70	80	87	90
90	82	67	46	22	-4	-31	-54	-73	-85	-90	-88	-78	-61	-38	-13	13	38	61	78	88	90	85	73	54	31	4	-22	-46	-67	-82	-90
89	75	50	18	-18	-50	-75	-89	-89	-75	-50	-18	18	50	75	89	89	75	50	18	-18	-50	-75	-89	-89	-75	-50	-18	18	50	75	89
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78	-4	-82	-73	13	85	67	-22	-88	-61	31	90	54	-38	-90	-46	46	90	38	-54	-90	-31	61	88	22	-67	-85	-13	73	82	4	-78
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73	-31	-90	-22	78	67	-38	-90	-13	82	61	-46	-88	-4	85	54	-54	-85	4	88	46	-61	-82	13	90	38	-67	-78	22	90	31	-73
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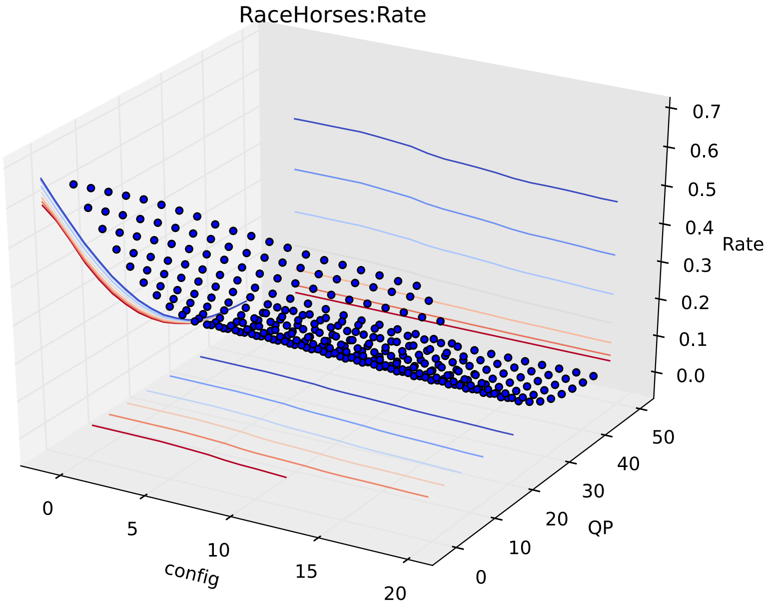
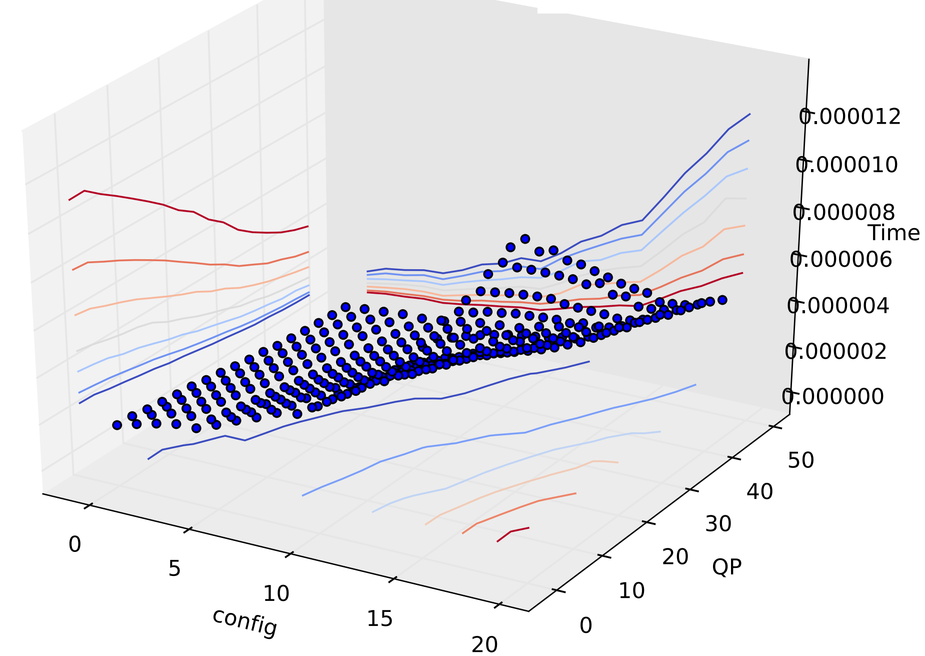
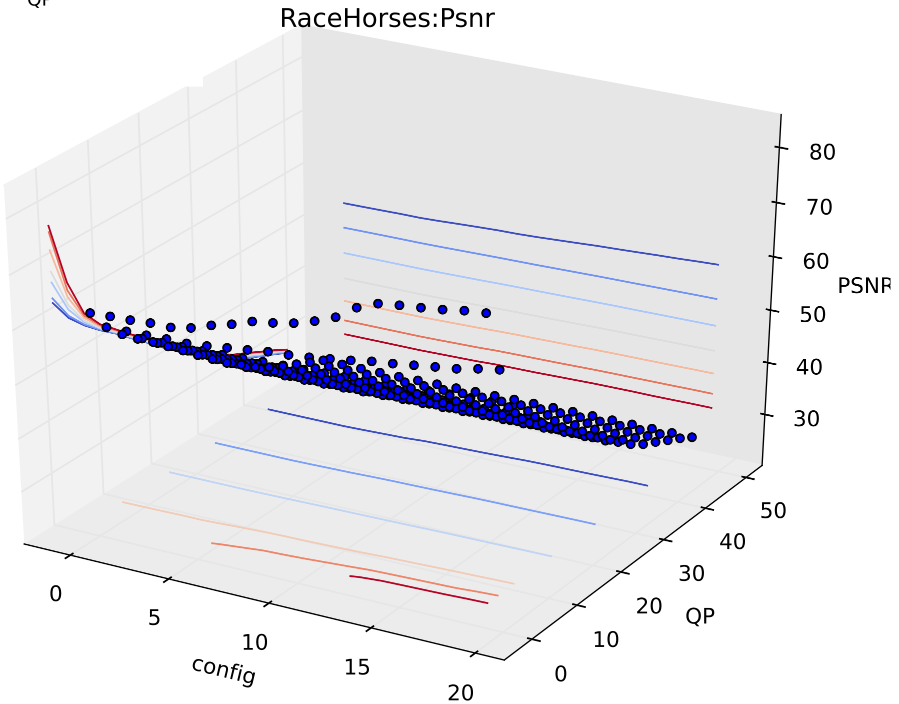
4	-13	22	-31	38	-46	54	-61	67	-73	78	-82	85	-88	90	-90	90	-90	88	-85	82	-78	73	-67	61	-54	46	-38	31	-22	13	-4

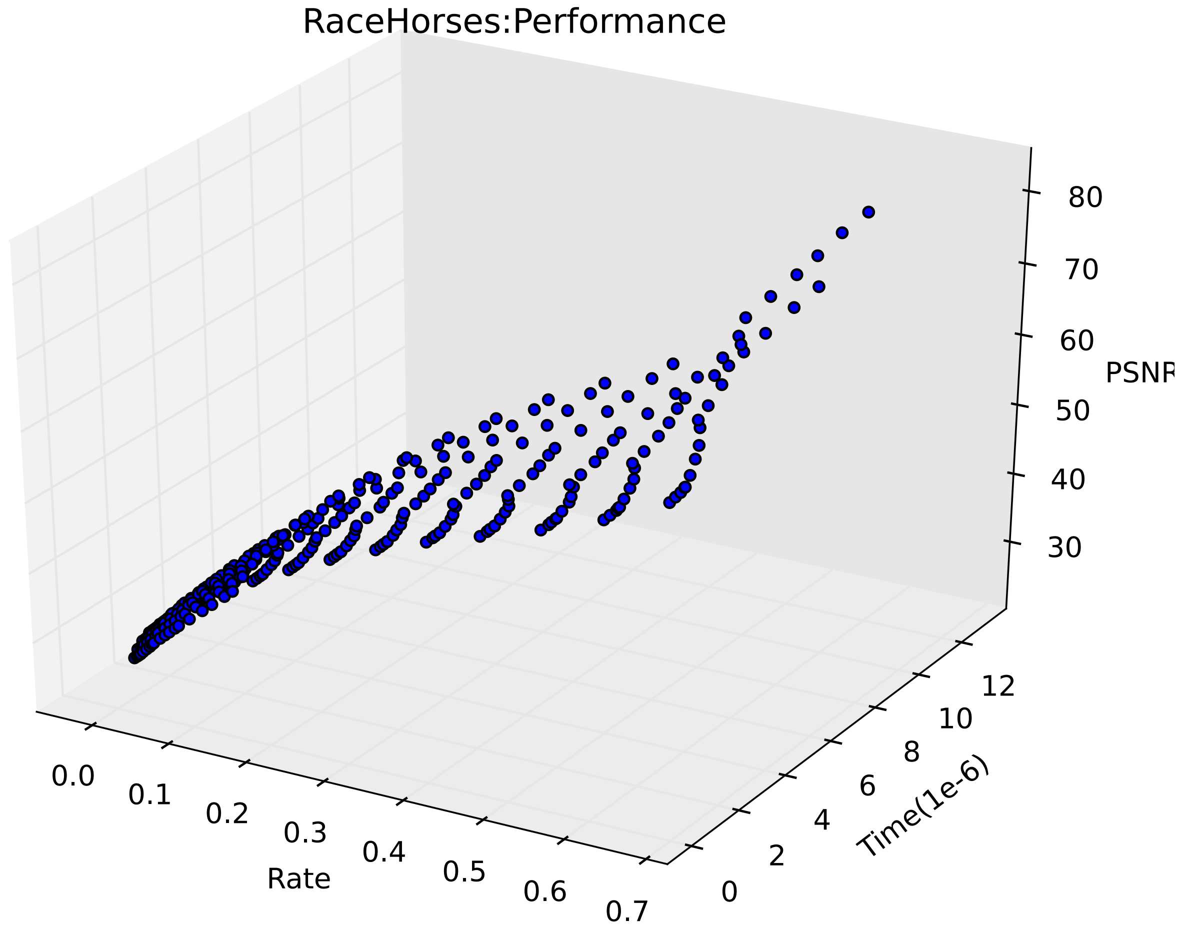
HEVC Intra-Pred (Config)


RaceHorses:Rate


RaceHorses:Time

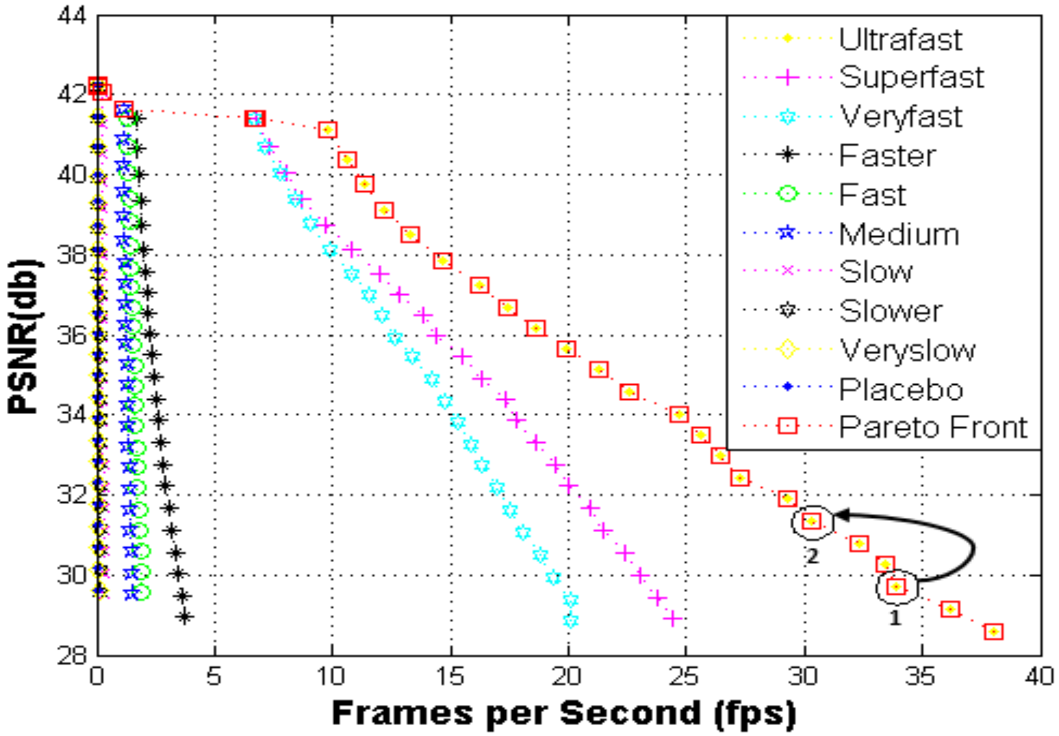

RaceHorses:Psnr

HEVC Intra-Pred (Space)



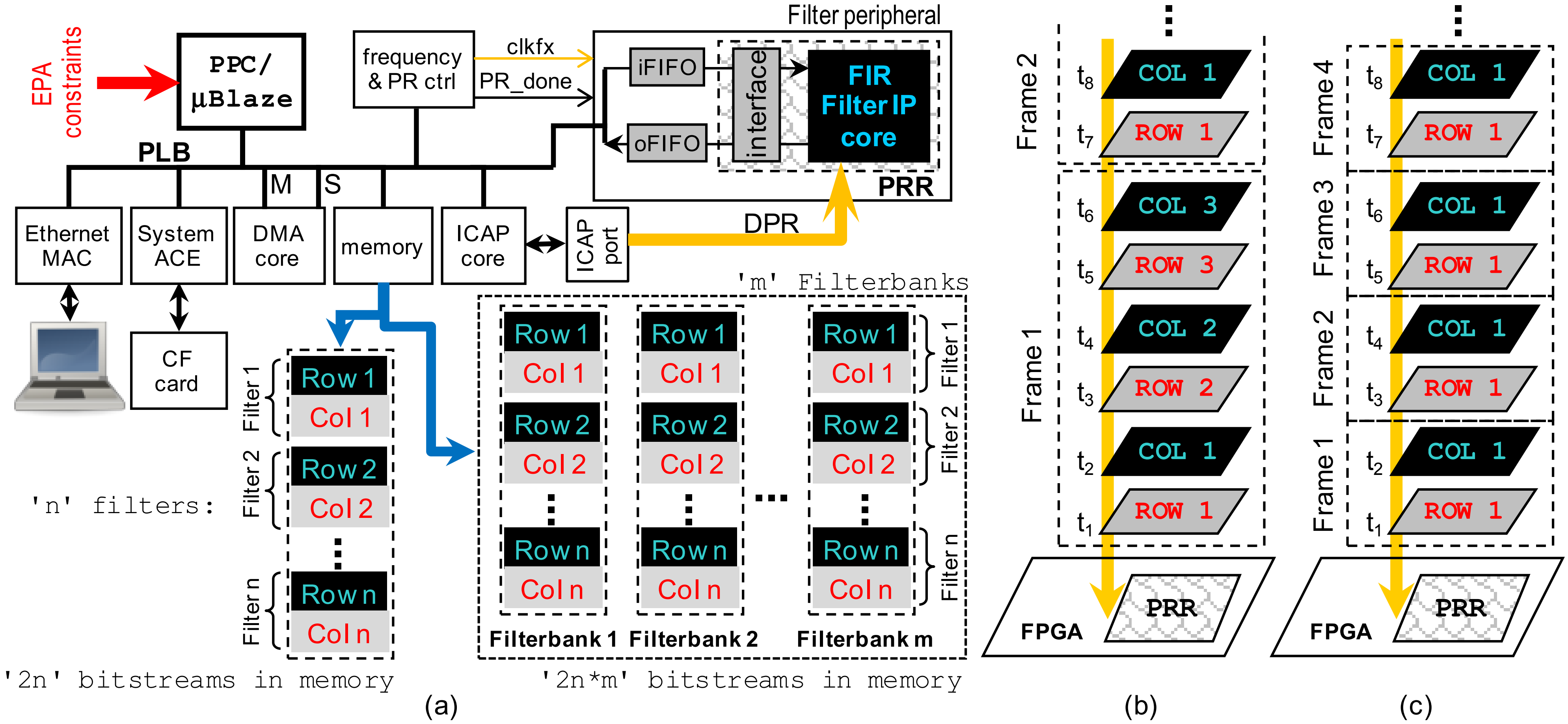
Adaptive Real-time HEVC

This is an emergency video example.

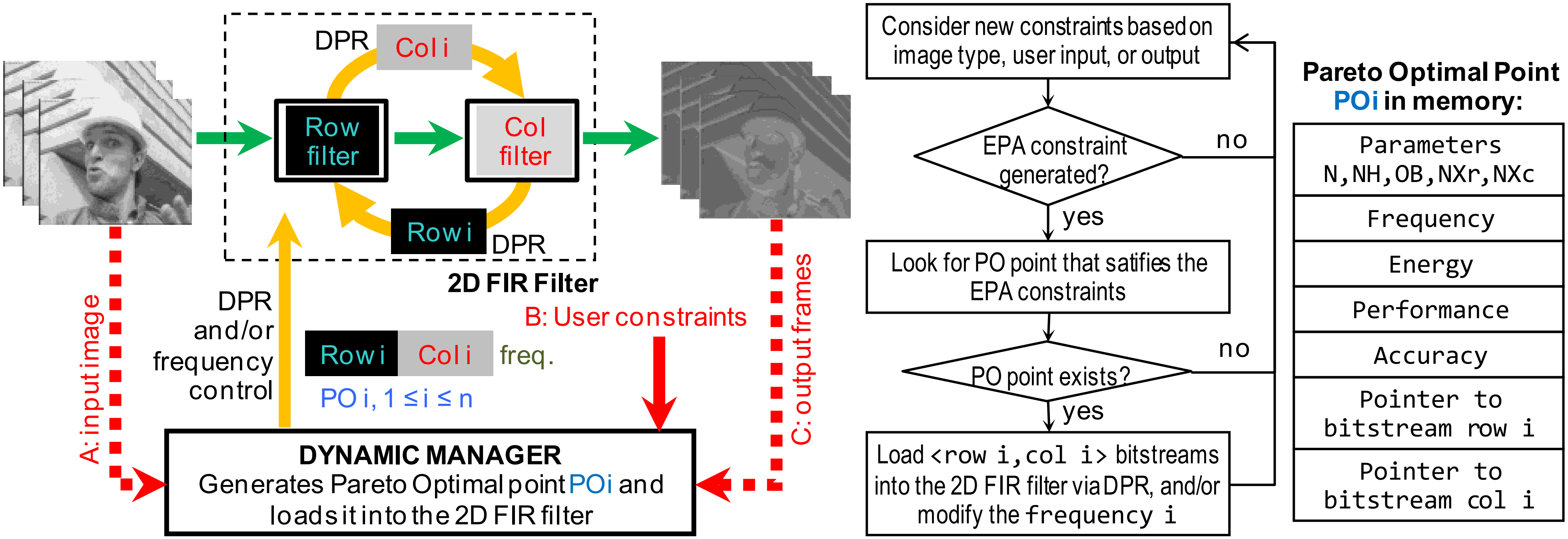


- Adaptation for the maximum video quality mode subject to real-time encoding that translates to frame-rate ≥ 25 fps and 3G available bandwidths.
- (1) BW ≤ 250 kbps to (2) BW ≤ 384 kbps (max 3G upload speed).
- Lower bandwidth: PSNR of 29.7 dB (33.88 fps @ 226 kbps)
- Second bandwidth: PSNR: 31.9 dB (29.29 fps@ 363.53 kbps).
- Encoding delay was 0.426 seconds with 6 core Xeon@2.26 GHz (WPP streams / pool / frames: 18 / 6 / 2 for x.265 encoding).

4. Video Image Analysis



Video Analysis: Filterbanks



(a)

Consider new constraints based on image type, user input, or output

EPA constraint generated?

no

yes

Look for PO point that satifies the EPA constraints

PO point exists?

no

yes

Load <`row i`,`col i`> bitstreams into the 2D FIR filter via DPR, and/or modify the frequency `i`

(b)

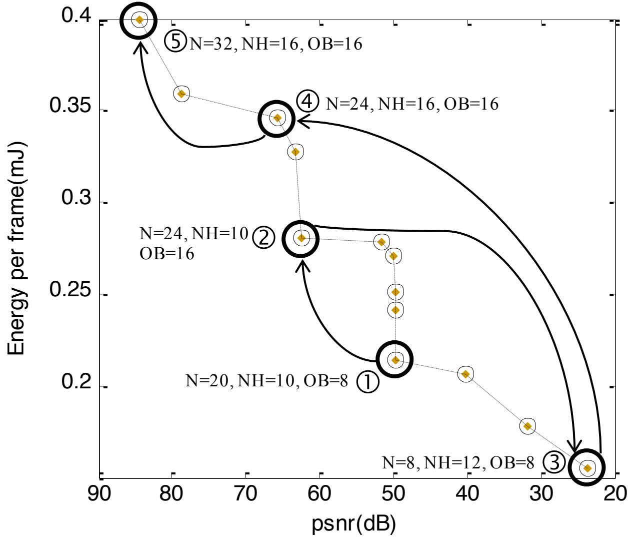
Pareto Optimal Point POi in memory:

- `Parameters N,NH,OB,NXr,NXc`
- `Frequency`
- `Energy`
- `Performance`
- `Accuracy`
- `Pointer to bitstream row i`
- `Pointer to bitstream col i`

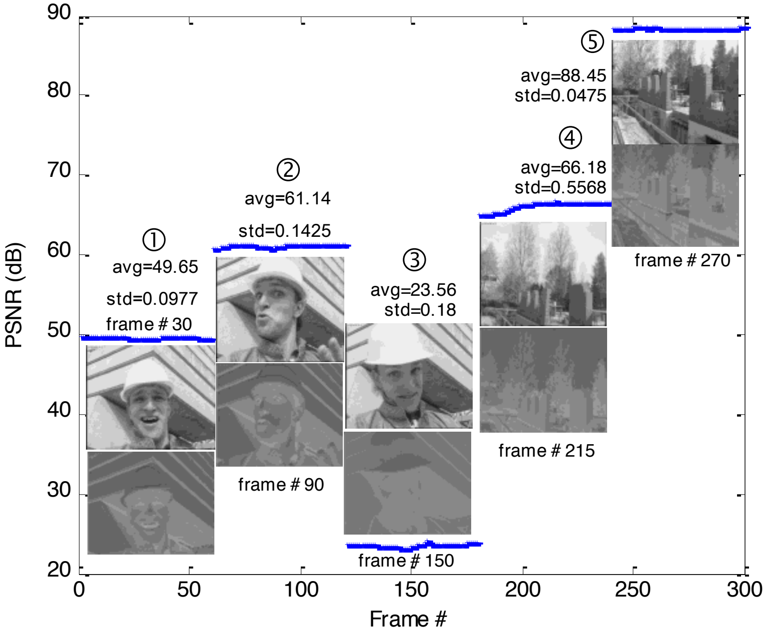
(c)

Autom. Analysis: Adaptive Acc.

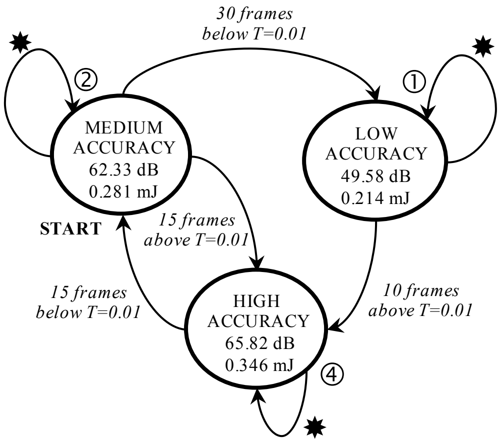
	① →	② →	③ →	④ →	⑤
Energy per frame Accuracy (psnr)	0.3 mJ 45dB	0.3mJ max	min --	min 65dB	-- max



(a)

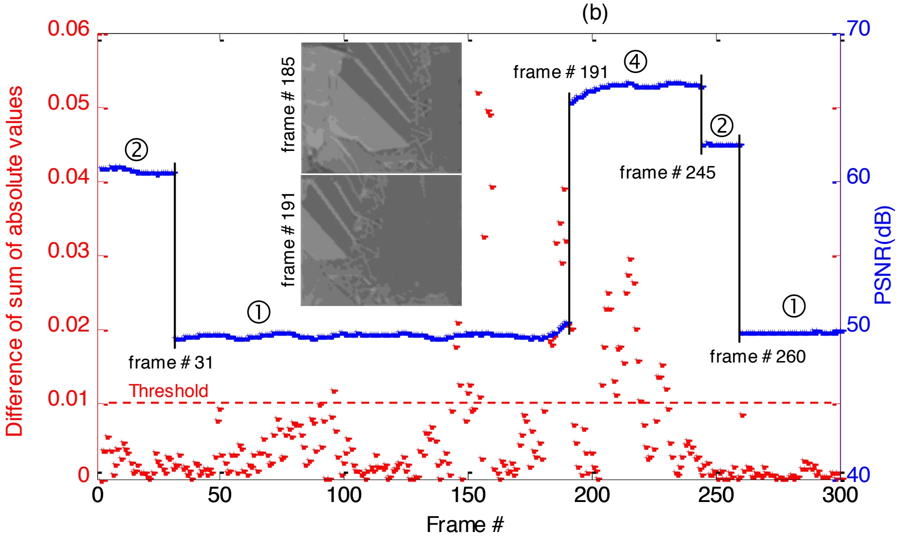


(b)



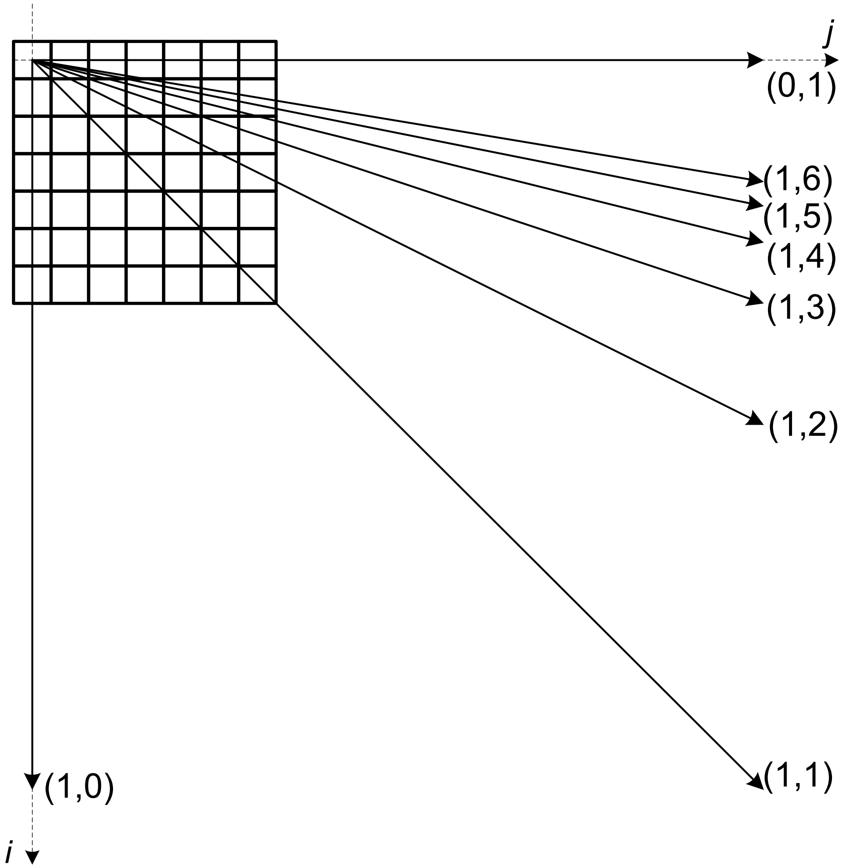
✸ If the conditions do not hold, stay in the current state

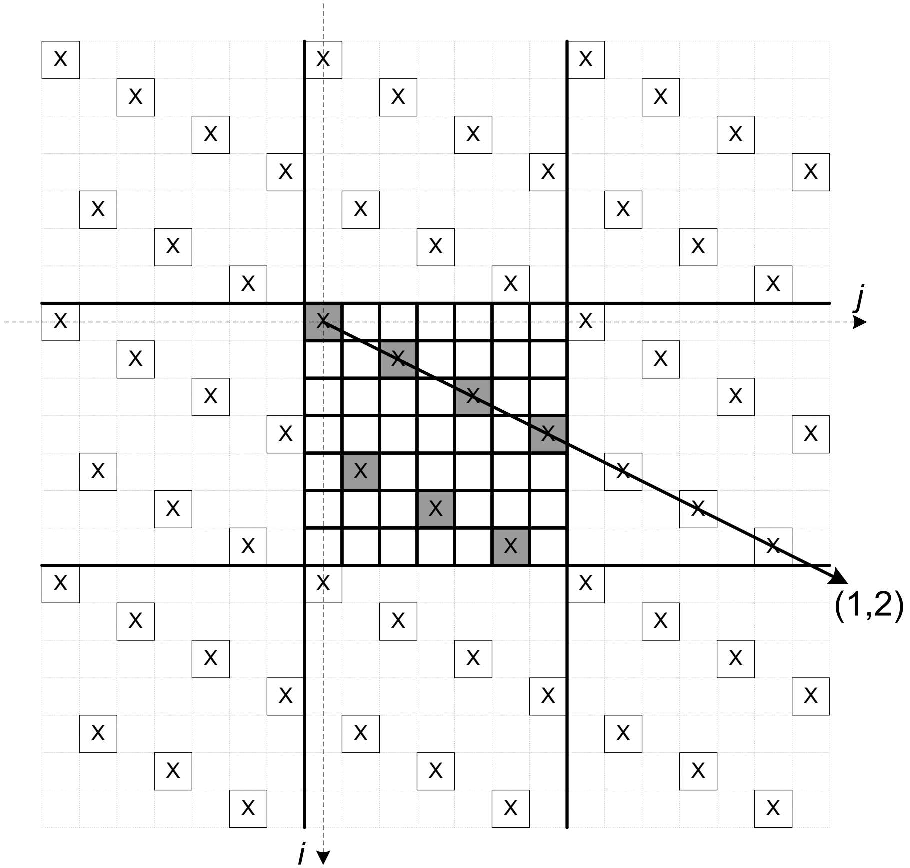
(c)



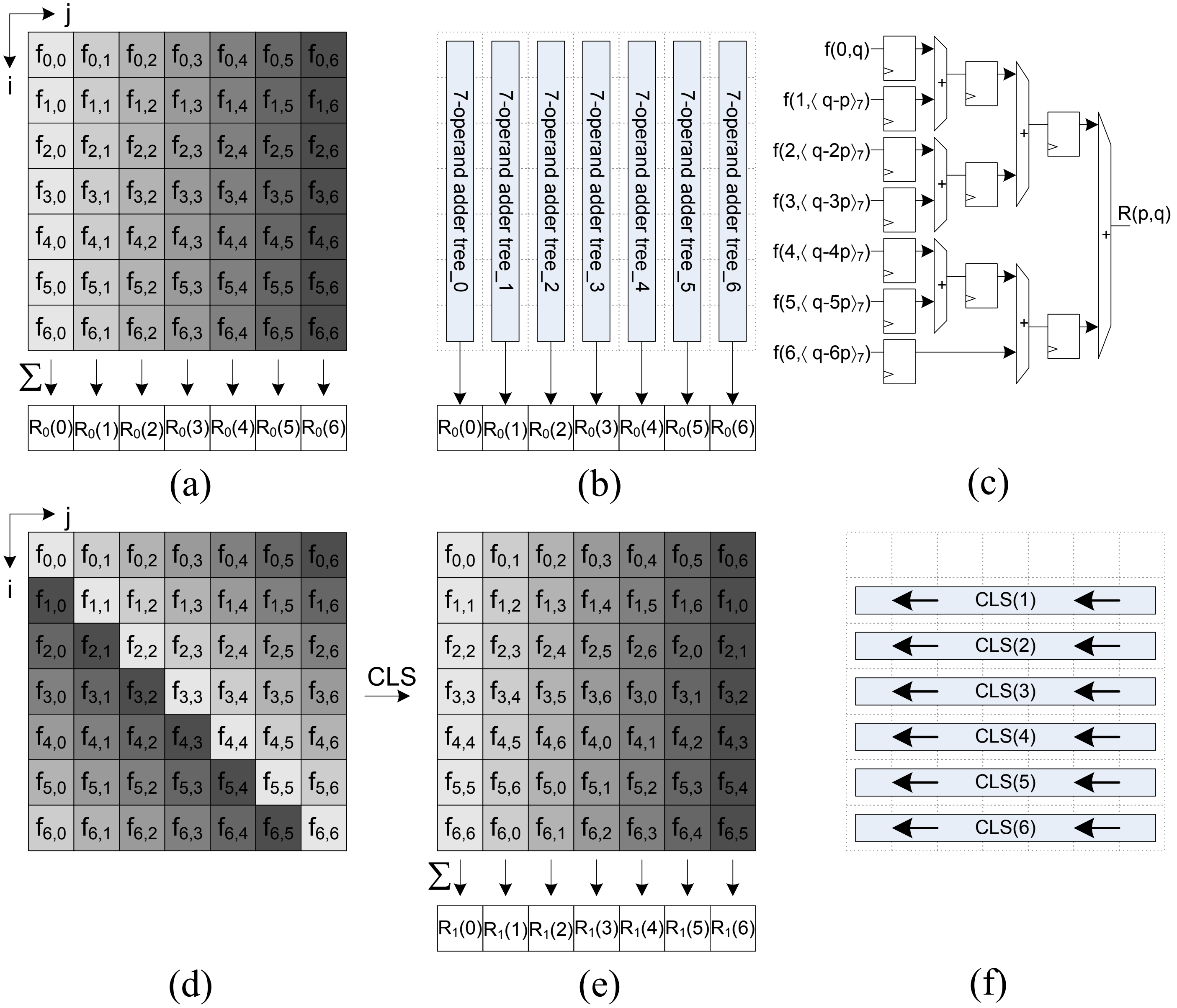
(d)

DPRT: Prime Directions





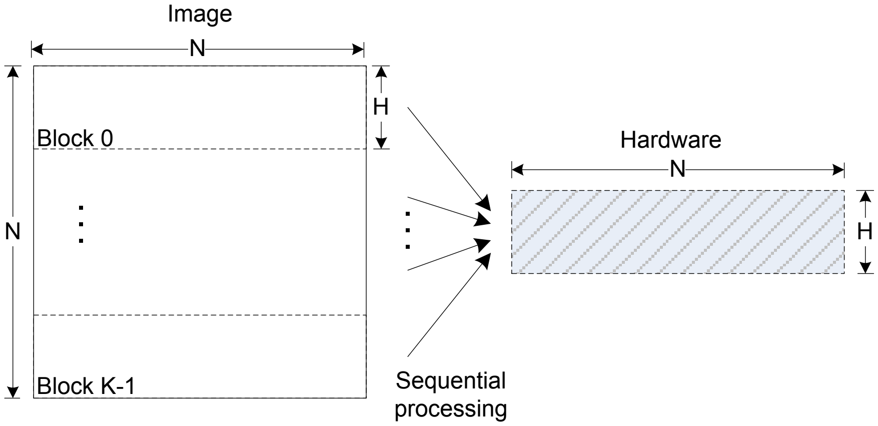
DPRT: New Architecture



$f_{0,0}$	$f_{0,1}$	$f_{0,2}$	$f_{0,3}$	$f_{0,4}$	$f_{0,5}$	$f_{0,6}$
$f_{1,0}$	$f_{1,1}$	$f_{1,2}$	$f_{1,3}$	$f_{1,4}$	$f_{1,5}$	$f_{1,6}$
$f_{2,0}$	$f_{2,1}$	$f_{2,2}$	$f_{2,3}$	$f_{2,4}$	$f_{2,5}$	$f_{2,6}$
$f_{3,0}$	$f_{3,1}$	$f_{3,2}$	$f_{3,3}$	$f_{3,4}$	$f_{3,5}$	$f_{3,6}$
$f_{4,0}$	$f_{4,1}$	$f_{4,2}$	$f_{4,3}$	$f_{4,4}$	$f_{4,5}$	$f_{4,6}$
$f_{5,0}$	$f_{5,1}$	$f_{5,2}$	$f_{5,3}$	$f_{5,4}$	$f_{5,5}$	$f_{5,6}$
$f_{6,0}$	$f_{6,1}$	$f_{6,2}$	$f_{6,3}$	$f_{6,4}$	$f_{6,5}$	$f_{6,6}$
$R_0(0)$	$R_0(1)$	$R_0(2)$	$R_0(3)$	$R_0(4)$	$R_0(5)$	$R_0(6)$

$f_{0,0}$	$f_{0,1}$	$f_{0,2}$	$f_{0,3}$	$f_{0,4}$	$f_{0,5}$	$f_{0,6}$
$f_{1,1}$	$f_{1,2}$	$f_{1,3}$	$f_{1,4}$	$f_{1,5}$	$f_{1,6}$	$f_{1,0}$
$f_{2,2}$	$f_{2,3}$	$f_{2,4}$	$f_{2,5}$	$f_{2,6}$	$f_{2,0}$	$f_{2,1}$
$f_{3,3}$	$f_{3,4}$	$f_{3,5}$	$f_{3,6}$	$f_{3,0}$	$f_{3,1}$	$f_{3,2}$
$f_{4,4}$	$f_{4,5}$	$f_{4,6}$	$f_{4,0}$	$f_{4,1}$	$f_{4,2}$	$f_{4,3}$
$f_{5,5}$	$f_{5,6}$	$f_{5,0}$	$f_{5,1}$	$f_{5,2}$	$f_{5,3}$	$f_{5,4}$
$f_{6,6}$	$f_{6,0}$	$f_{6,1}$	$f_{6,2}$	$f_{6,3}$	$f_{6,4}$	$f_{6,5}$
$R_1(0)$	$R_1(1)$	$R_1(2)$	$R_1(3)$	$R_1(4)$	$R_1(5)$	$R_1(6)$

Recent Work: Scalable FDPRT



It allows effective implementations based on different constraints on the hardware resources and image sizes (powers of 2 + prime).

Running time:

$$\left\lceil N/2^h \right\rceil N + 2N + h \text{ clock cycles}, \quad h = 1, \ldots, \lceil \log_2 N \rceil$$

For $h = \lceil \log_2 N \rceil$ we obtain the fastest processing time with the maximum resource usage:

$$3N + \lceil \log_2 N \rceil \text{ clock cycles}$$

Spilt by 2: 2N cycles to load + N for transpose.

For $h = 1$ we obtain the lowest resource usage and the slowest running time:

$$\lceil N/2 \rceil N + 2N + 1 \text{ clock cycles}$$

Recent Work: Fast 2D Circular Convolution

Let $g(x, y)$ and $h(x, y)$ be two 2D discrete functions, the 2-D cyclic convolution of g and h is given by:

$$f(u, v) = g(x, y) \otimes_2 h(x, y)$$

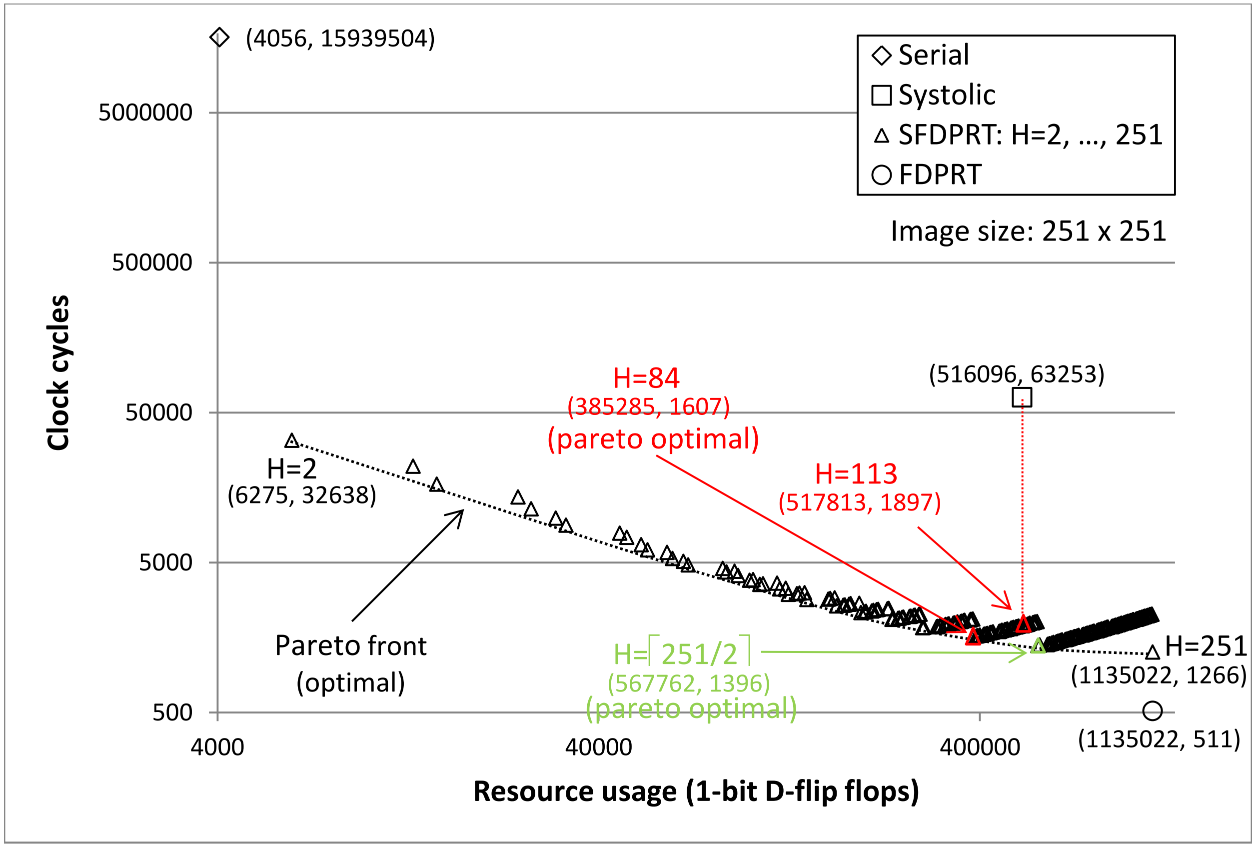
where, $x, y, u, v \in \{0, 1, \ldots, N-1\}$, N prime, and $\otimes_2$ denotes the 2D cyclic convolution operator.

Applying the DPRT, the $\otimes_2$ operator becomes $\otimes_1$: 1D cyclic convolution.

$$\Re\{f(u, v)\} = \Re\{g(x, y))\} \otimes_1 \Re\{h(x, y))\}$$

Cyclic convolution using:	**Computational Complexity**
Definition	$O(N^4)$
Discrete Fourier Transform	$O(N^2 * \log_2 N + N^2)$
FDPRT	$O(N+\text{ceil}(\log_2 N) + N^2)$
Scalable FDPRT	$O(\text{ceil}(N/2^h) * N + 2N + h + N^2)$

DPRT: Pareto-Optimal HW



Conclusion

- Example Applications Demonstrate Promise
- Approach can handle joint software-hardware optimization as well as software-only optimization
- Current research focused on automatic constraint generation and real-time Pareto-front estimation without the need to pre-compute over a training set