CAMED: Complexity Adaptive Motion Estimation & Mode Decision for H.264 Video

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Outline

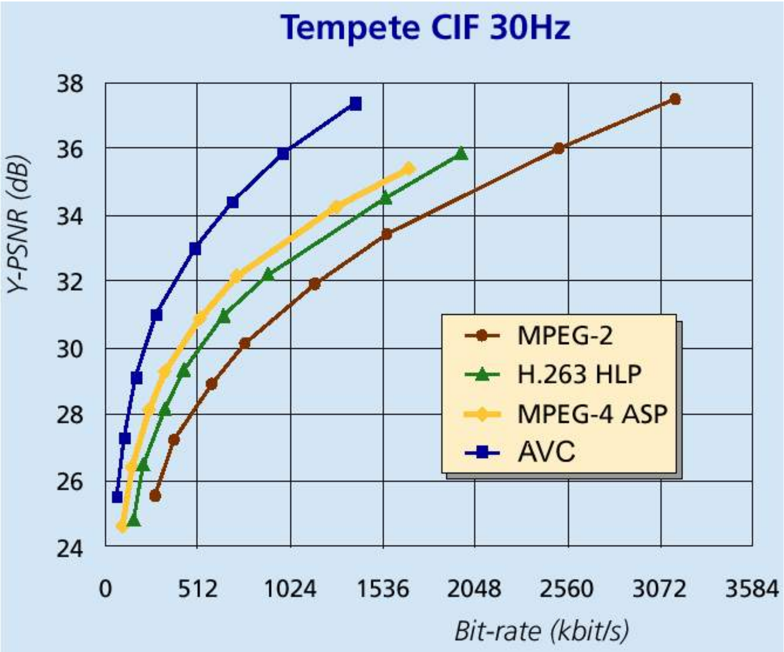
- Complexity aware H.264 coding
- CAMED
  - Rate-Distortion-Complexity video coding
  - Complexity cost function
  - Complexity control
- Experiment results
- Conclusions & future work

H.264: Emerging Video Standard

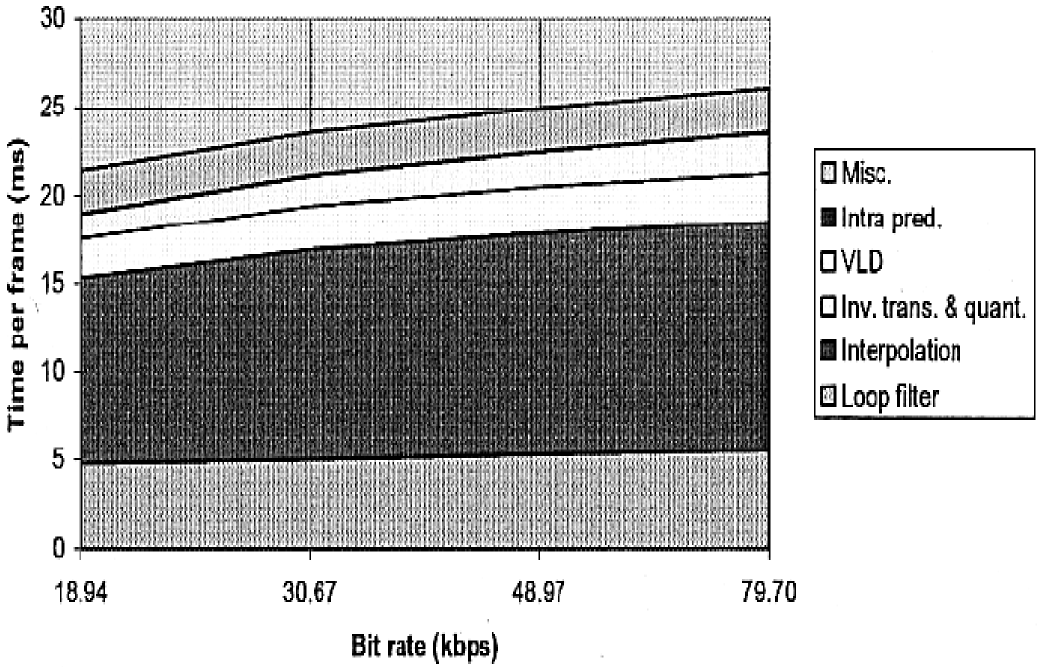
- More efficient motion prediction
  - Variable block size motion compensation (as small as 4 x 4)
  - Quarter pixel interpolation
  - Multiple reference frames (up to 5)
  - Decoupling of referencing order from display order
  - Directional spatial prediction for intra coding
  - SKIP/DIRECT Mode
- Improved coding efficiency
  - Small block-size transform (4 x 4 integer transform)
  - Lossless inverse transform
  - Context-based adaptive binary arithmetic coding (CABAC)
  - Switching P (SP) and switching I (SI) pictures

Complexity Issue In H.264

- Much better quality, with much higher complexity



[Schäfer'03]



[Lappalainen'03]

Complexity Aware H.264 Coding

- Important for mobile video solutions
- H.264: Emerging coding standard
  - Much higher quality
  - Much higher complexity
- Complexity constrained video coding

$$
\begin{aligned}
&\min D(\mathbf{P}),\\
&s.t., R(\mathbf{P}) \le R_T, \quad \mathbf{P}: QP, MV, Mode, ?\\
&\quad C(\mathbf{P}) \le C_T
\end{aligned}
$$

Approaches for Comp. Reduction

- Hardware level
  - Hardware architecture (MMX, SIMD [Chen'04])
  - Low power chip (Advanced voltage scaling [ARM'03])
  - High capacity battery [GIT]

- Encoder complexity
  - Fast motion estimation (FME) [Li'05, Tourapis'03]
  - Fast mode decision (FMD) [Zhu'05, Peng'05]
  - Fast reference frame selection [Su'04]
  - Adaptive I-B-P GOP structure [Ray'04]
  - SAD (Sum of Absolute Difference) complexity modeling [He'04]

- Decoder complexity
  - Smart inverse DCT [Ortega'00]
  - Interpolation approximation [Wang'05]
  - Implementation optimization (buffer reusage, assembly coding)
  - Complexity Adaptive ME & MD (CAMED)

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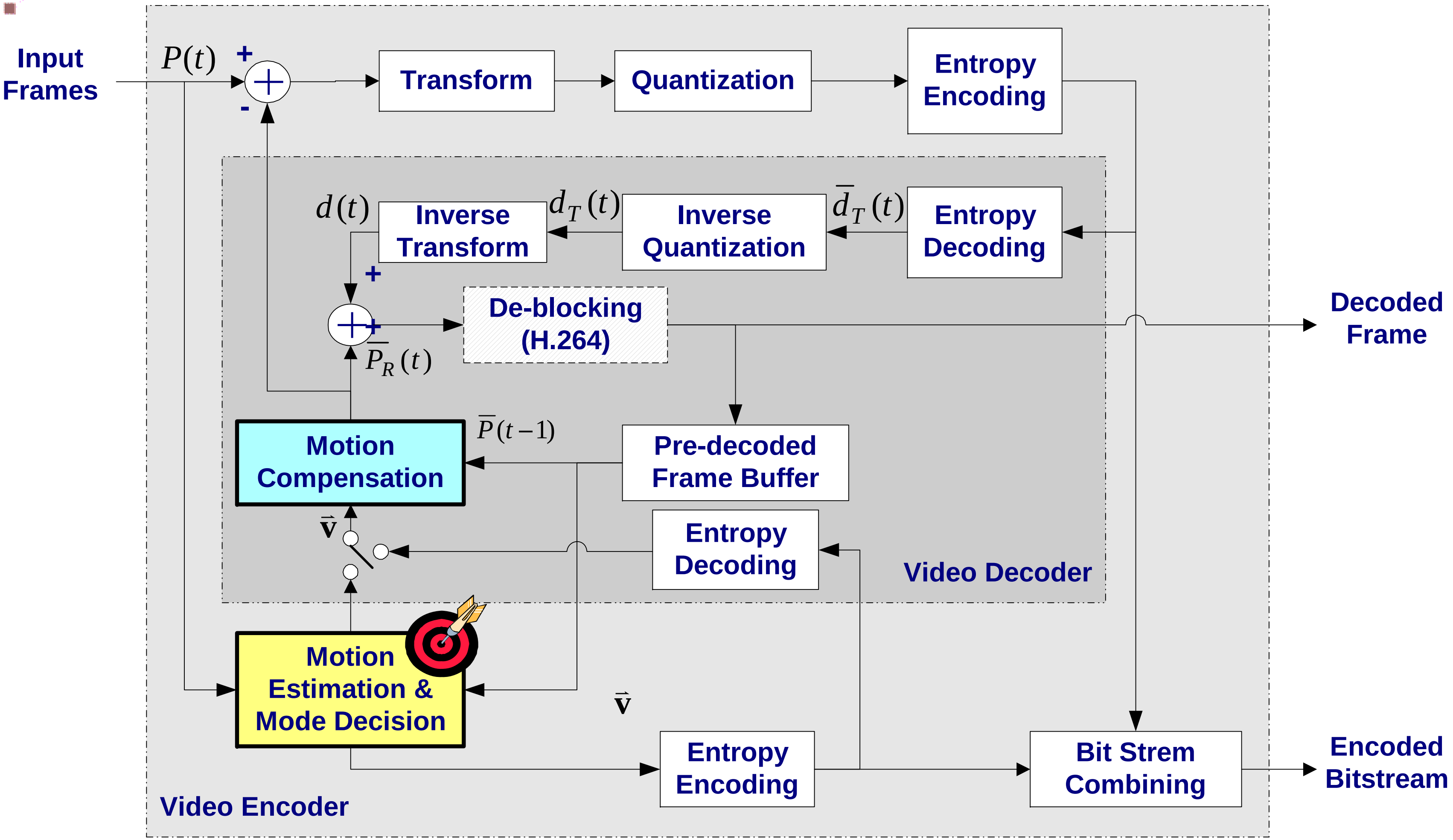
CAMED: Philosophy



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CAMED: Highlight

- Develop an encoding algorithm that achieves both high video quality and low decoding complexity
- Addressed the most significant module (Motion Compensation) in decoders, so that the complexity reduction is efficient.
- Nothing need to be done in decoders, and the extra cost in encoders is trivial
- Full standard compliant
- The proposed method can be a valuable complement for hardware-level and encoder-level solutions
- Very promising for mobile video applications.

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R-D-C Optimization

- R-D-C Lagrange optimization

$$\mathbf{V}_C^*(B,M) = \underset{\mathbf{V}\in\sup\{\mathbf{V}\}}{\arg\min}\; J_{MOTION}^{R,D,C}(\mathbf{V}|B,M)$$

$$= \underset{\mathbf{V}\in\sup\{\mathbf{V}\}}{\arg\min}\left\{ J_{MOTION}^{R,D}(\mathbf{V}|B,M) + \gamma_{MOTION} C_{MOTION}(\mathbf{V}|B,M)\right\}$$

$$M_C^*(MB,QP) = \underset{M\in\sup\{M\}}{\arg\min}\; J_{MODE}^{R,D,C}\left(M|MB,QP\right)$$

$$= \underset{M\in\sup\{M\}}{\arg\min}\left\{ J_{MODE}^{R,D}\left(M|MB,QP\right) + \gamma_{MODE} C_{MODE}\left(M|MB,QP\right)\right\}$$

$$\gamma_{MOTION} = \sqrt{\gamma_{MODE}}$$

Complexity Cost Function

- Pixel-based interpolation operation

$$c_P(\mathbf{V}) = \begin{cases} 0 & \mathbf{V} \text{ is integer MV} \\ e_6 & \mathbf{V} \text{ is subpixel } b,h \\ e_6 + e_2 & \mathbf{V} \text{ is subpixel } a,c,d,n \\ 2e_6 + e_2 & \mathbf{V} \text{ is subpixel } e,g,p,r \\ 7e_6 & \mathbf{V} \text{ is subpixel } j \\ 7e_6 + e_2 & \mathbf{V} \text{ is subpixel } i,f,k,q \end{cases}$$

G	a	b	c	H
d	e	f	g	
h	i	j	k	m
n	p	q	r	
M		s		N

- Can be further simplified counting 7-tap interpolations.

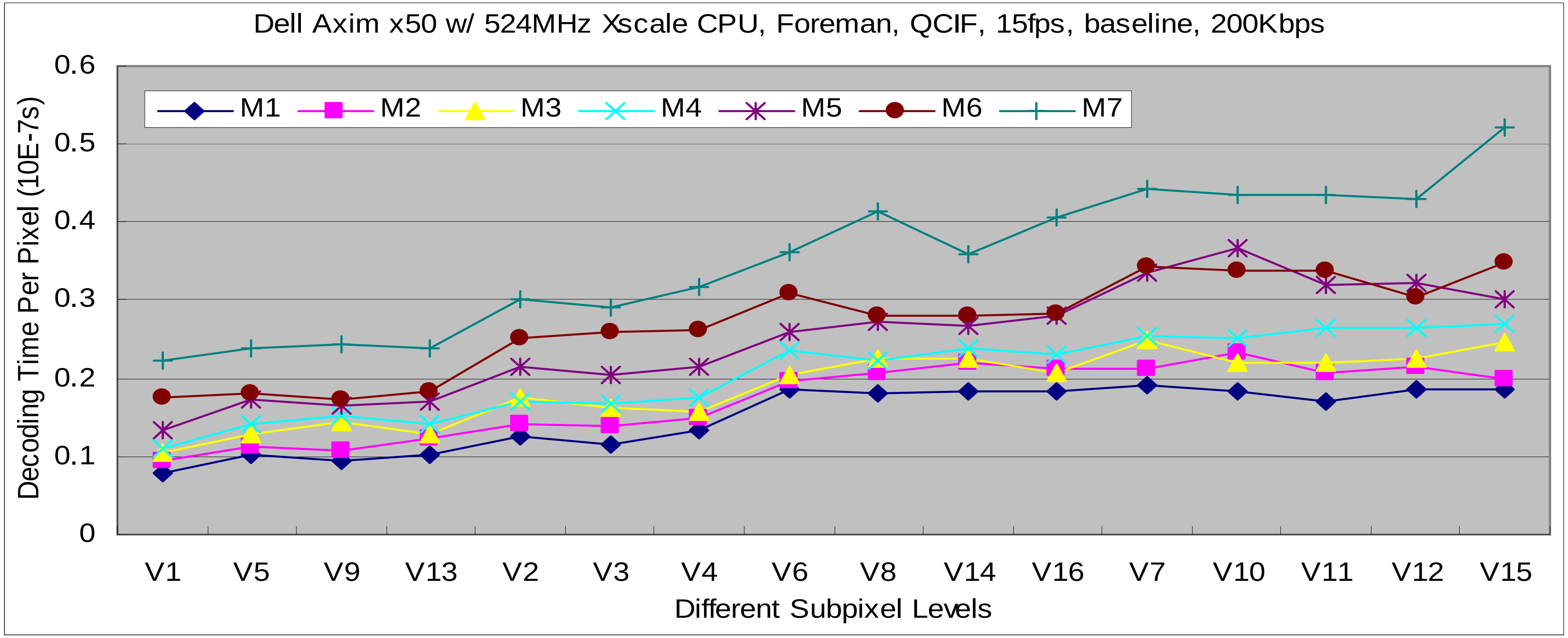
Complexity Cost Function (cont.)

- Block-based interpolation operation

Mode	Integer	1 6-tap	2 6-tap	7 6-tap
Skip/Direct	0	256	512	592
16x16	0	256	512	592
16x8	0	128	256	296
8x16	0	128	256	296
8x8	0	64	128	168
8x4	0	32	64	84
4x8	0	32	64	84
4x4	0	16	32	52
Intra	0	0	0	0

Complexity Cost Function (cont.)

- Complexity benchmark
  - Real time AVC decoder in Dell Axim x50 PDA



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Complexity Cost Function (cont.)

- Modeling based on complexity benchmark

$$c(\mathbf{v}, M) = b_M^{-p}\left(n_{6,\mathbf{v}} c_6 + n_{2,\mathbf{v}} c_2 + c_l\right)$$

- Content-independent: the complexity is mainly decided by the arithmetic calculations
- Can be summarized into look-up table to reduce encoding cost
- Reflects the actual computing complexity, including not only interpolation, but also other cost rather than interpolation such as memory access and logic flow.

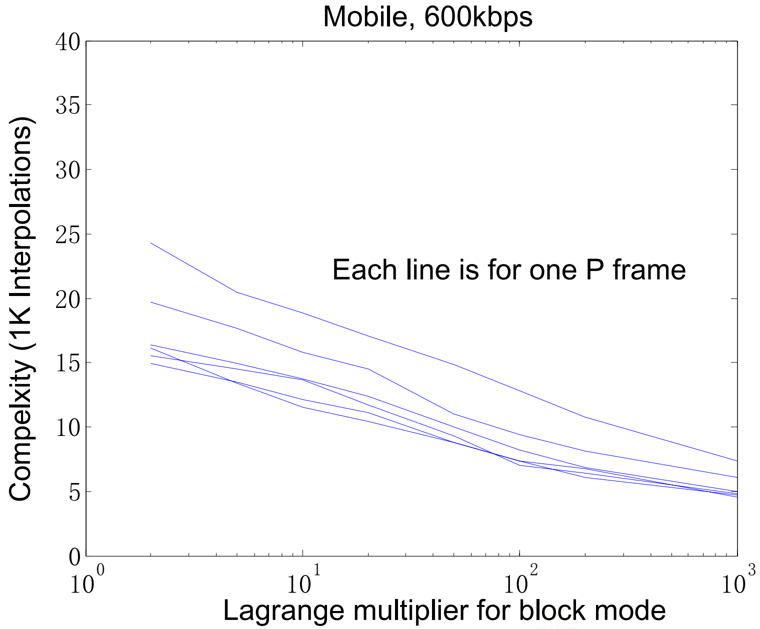
Complexity Control

- The procedure to adjust coding parameters so that the complexity level meets the target requirement.
  - Similar to rate control
  - Control parameter: Lagrange multiplier $\gamma_{MOTION}, \gamma_{MODE}$

- Complexity modeling

$$C(\gamma_{MODE}) = D\left(K_1 \ln(\gamma_{MODE}) + K_0\right)$$

$$\gamma_{MODE}(t) = \exp\left\{\frac{C(t) - K_0 D(t)}{K_1 D(t)}\right\}$$



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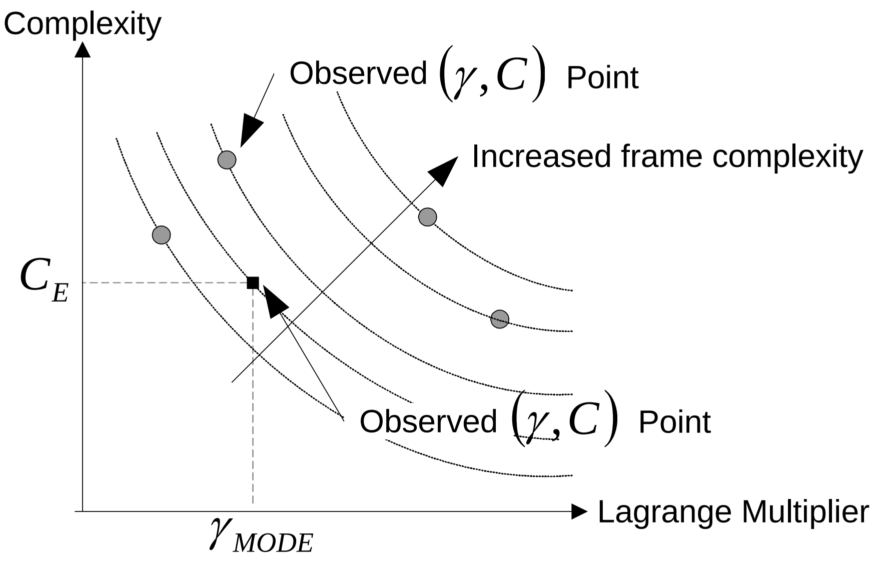
Complexity Control (cont.)

- Model estimation
  - Collect complexity stat using sliding window
  - Estimate model parameters through regression

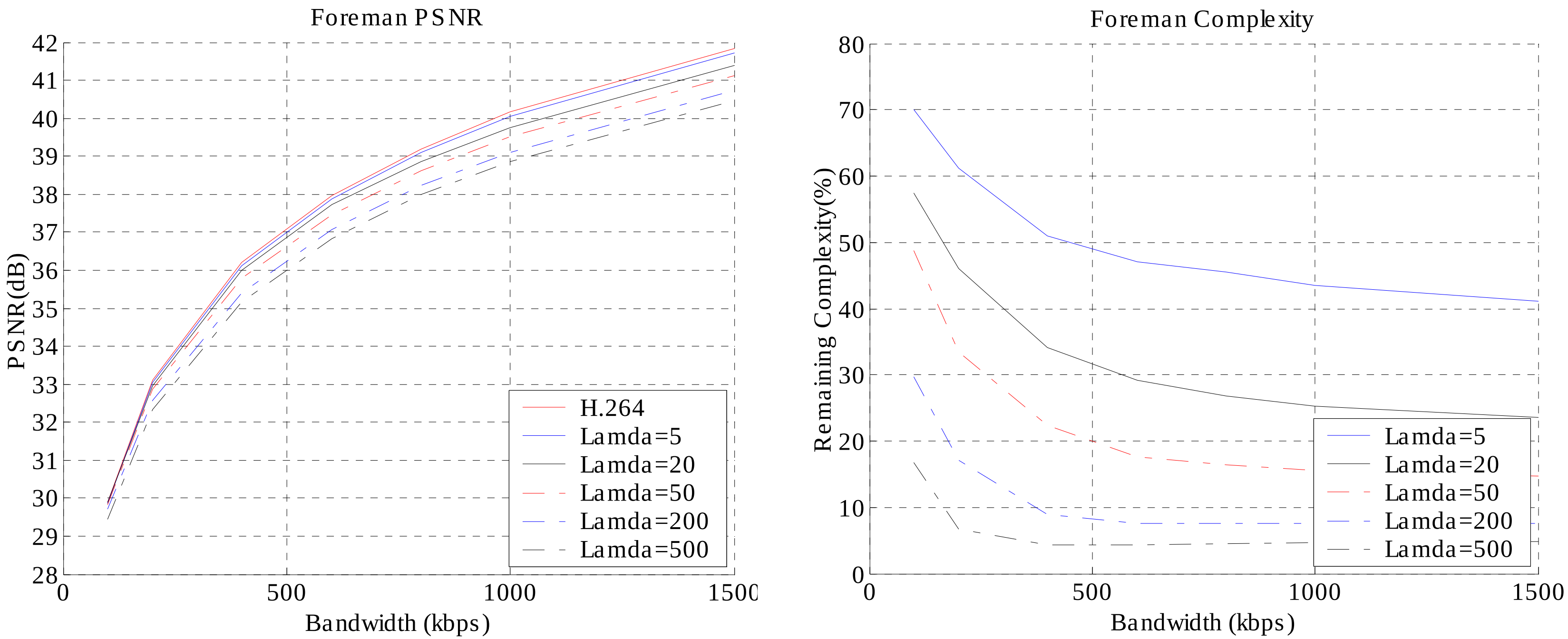


- Buffer management
  - Use complexity buffer to simulate the complexity usage status on the decoder side
  - Estimate of available resource, adjust the parameters, and avoid issues of buffer overflow or underflow

Experiment Setup

- Environment
  - Software: H.264 JM 8.2
  - Sequences: *Akiyo*, *Foreman*, *Stefan*, *Mobile*
  - Resolution: QCIF/CIF
  - Profile: Main/Baseline
  - Bit rate: 100kbps~1Mbps
  - Block mode: all on
  - Direct mode: temporal
  - Motion estimation search range: 32 pixels

R-D-C Optimization



Up to 60% 6-tap interpolation can be saved while keeping the video quality almost intact (quality difference less than 0.2dB)

Demonstration

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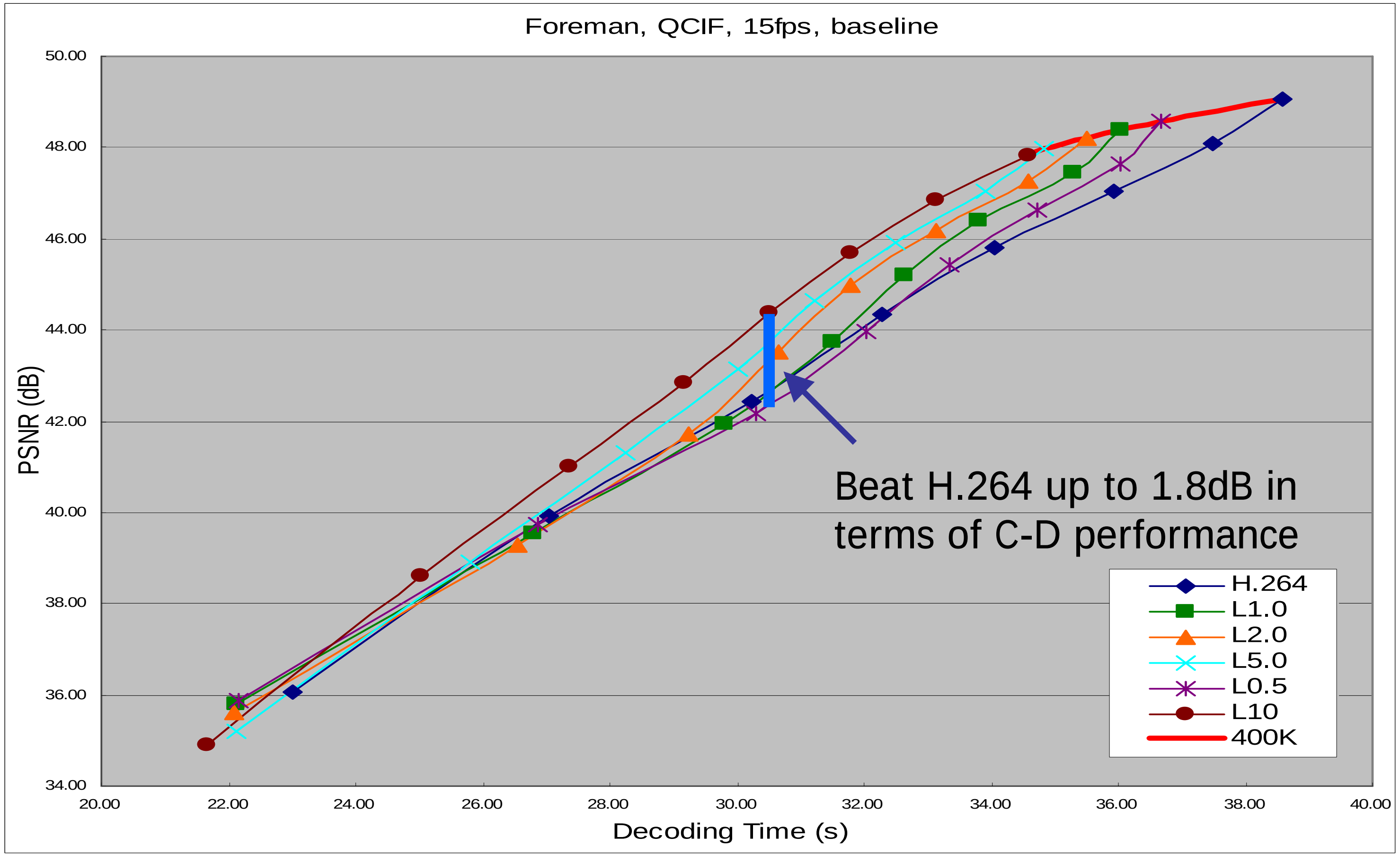
Results: Complexity Benchmark



Dell Axim x50

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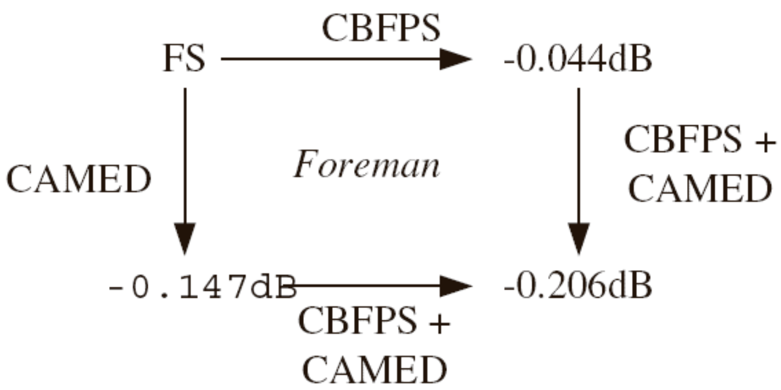
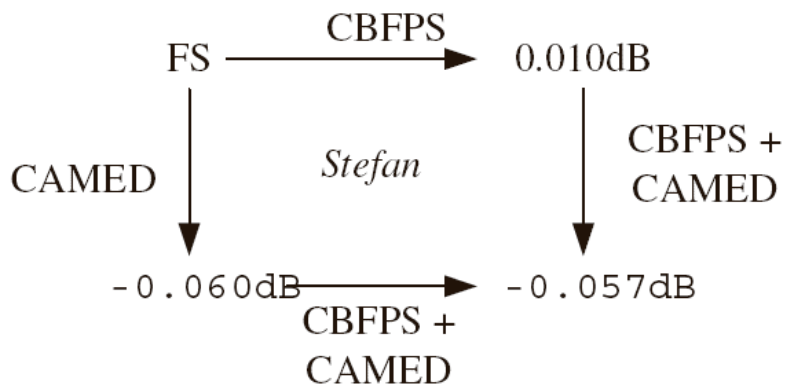
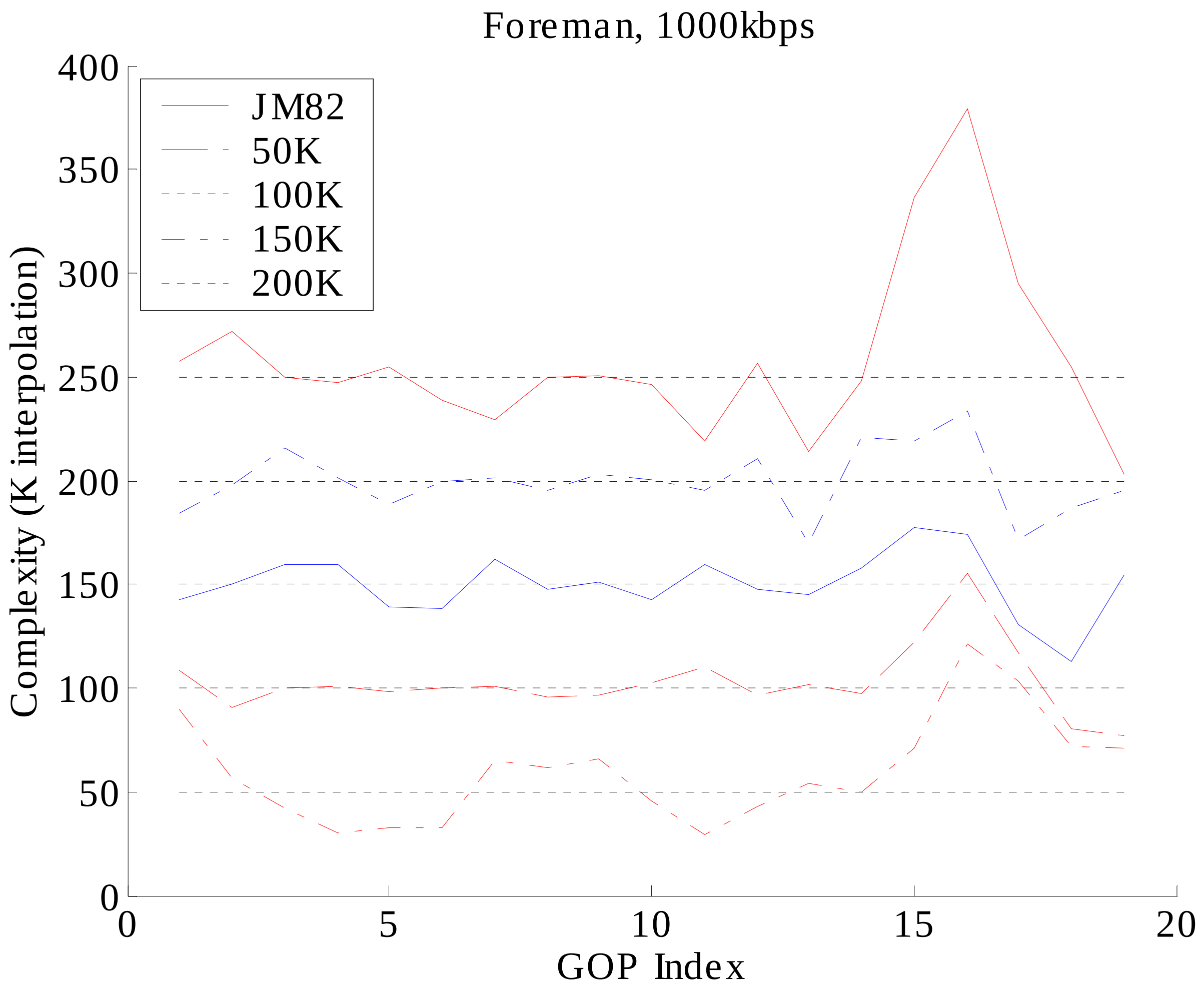
Results: Compatibility w/ FME

Foreman	PSNR(dB)†	Encoding Saving♮	Decoding Saving♯
FS	36.024	0.00%	0.00%
CBFPS	-0.044	61.80%	17.39%
CAMED $\gamma_{MODE} = 10$	-0.147	0.00%	70.08%
CBFPS+$\gamma_{MODE} = 10$	-0.206	64.75%	74.28%
CAMED $\gamma_{MODE} = 50$	-0.312	0.00%	85.63%
CBFPS+$\gamma_{MODE} = 50$	-0.390	66.09%	86.49%





Results: Complexity Control



Results: Complexity Control

Target Complexity (6-tap Interpolation)		5K	10K	20K	30K	40K
Foreman	Complexity control error (%)	37.07	5.00	1.50	3.38	3.09
	Complexity saving (%)	88.06	81.70	65.67	45.95	28.14
	Quality degradation (dB)	0.22	0.16	0.09	0.03	0.03
Stefan	Complexity control error (%)	39.38	19.45	0.32	0.26	0.37
	Complexity saving (%)	88.07	86.21	65.64	48.49	31.25
	Quality degradation (dB)	0.40	0.30	0.09	-0.03	0.06
Mobile	Complexity control error (%)	114.97	7.48	0.65	1.34	4.73
	Complexity saving (%)	81.89	81.89	66.08	50.13	35.79
	Quality degradation (dB)	0.40	0.40	0.17	0.14	0.06

CIF, 30fps, 100kbps

Conclusions & Future Work

- Proposed CAMED for complexity-efficient H.264 coding
- Applied rigorous R-D-C optimization framework
- Defined several complexity cost functions
- Proposed the algorithm of complexity control
- Performance Validated through extensive simulation experiment

- Future work
  - Theoretical analysis on the relationship between the complexity level and the control parameter (i.e., the Lagrange multiplier)
  - Considering hardware acceleration (such as MMX, SSE)
  - More efficient complexity modeling and complexity control

THANK YOU!

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