H.264 Video Quality Optimizations

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Outline

- Introduction
- Background
- Optimal Configuration of Video Encoding
- Downhill Simplex Search Method
- Video Quality Metric (VQM)
- Example 1: MB Level Adaptive Quantization
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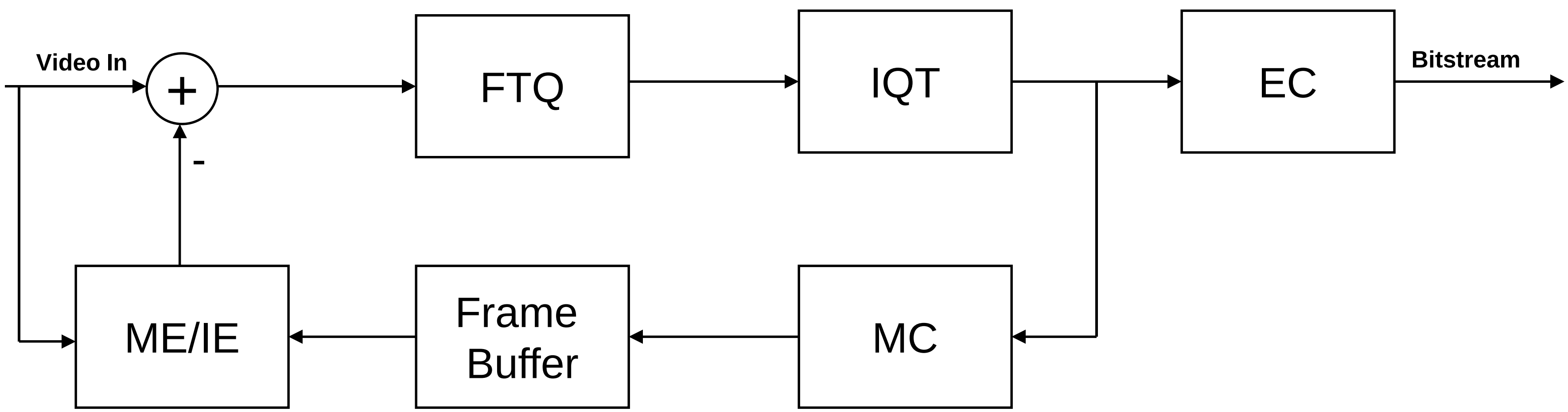
Introduction

- Video codecs such as MPEG-4 AVC / ITU-T H.264 have many encoder parameters to control
- A systematic framework to optimize encoder parameters is indispensable for optimal video encoding
- Choice of video quality metric is critical
- Determining optimal video encoding parameters is formulated as an optimization problem: maximize expected video encoding quality under constraints such as video quality, target bitrate, computation, memory bandwidth, etc.

Background
Motion Compensated Video Coding



FTQ: Forward Transform Quantization

IQT: Inverse Quantization Transform

EC: Entropy Coding

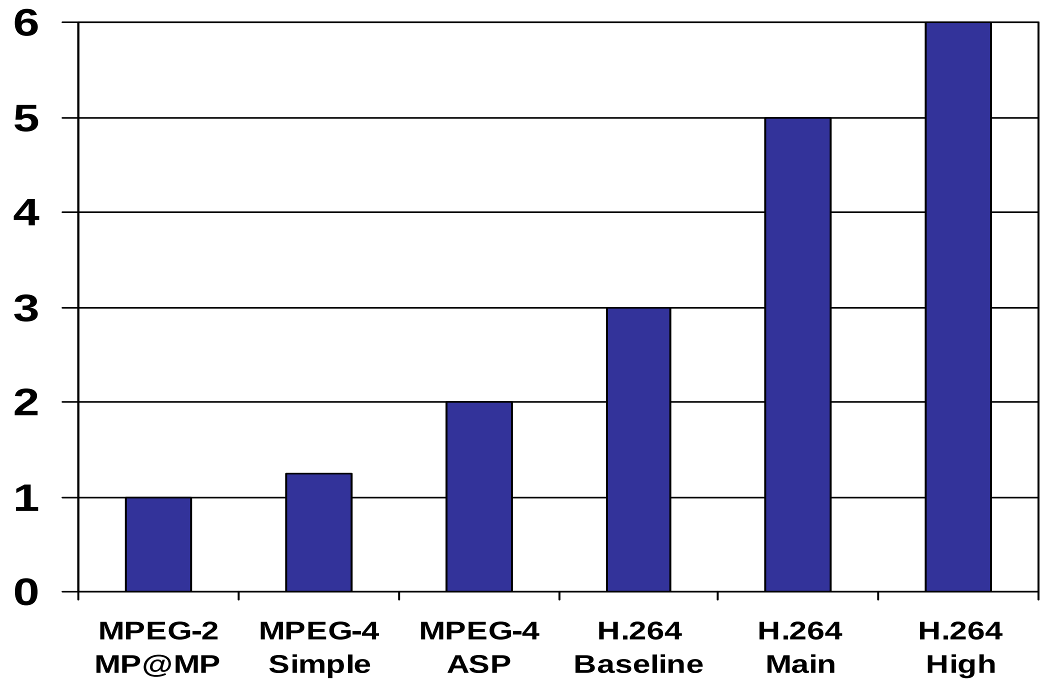
MC: Motion Compensation

ME/IE: Motion Estimation/Intra Estimation

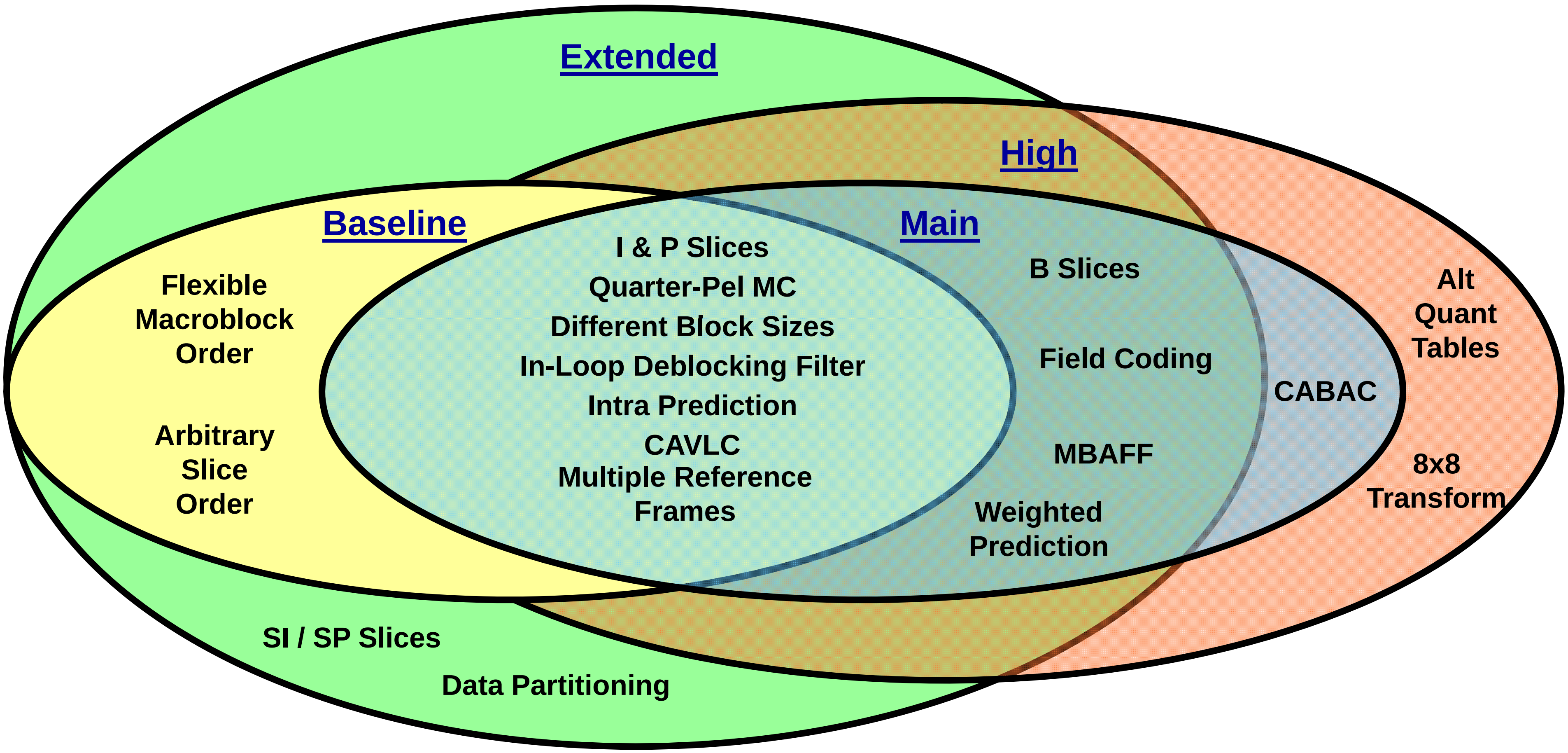
Background
MPEG-2 vs. AVC/H.264/MPEG-4 Part 10

- H.264 offers 2-3X bit rate reduction for the same quality compared to MPEG-2
- The added performance comes with higher encoder complexity

Normalized Codec Computing Requirements



H.264/AVC Tools/Profiles



H.264/AVC Encoder Parameters

- **System design parameters**
  - Level and profile, Group Of Pictures (GOP) structure
  - Entropy coding mode: CAVLC / CABAC, Number of reference frames, Interlace coding support, etc.
- **Encoder internal parameters**
  - Motion search range and algorithm, intra / inter encoding partition size and mode decision,
  - Intra prediction mode decision, PAFF and MBAFF decisions, MB level quantization parameters, etc.
- **User-controlled external parameters**
  - Deblocking filter strength, quantization scaling matrices,
  - quantization rounding offsets, Lagrangian multipliers for RD optimization, various thresholds to bias mode decision, etc.

Framework for Optimal Configuration of Video Encoding

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Formulated as maximizing the expected video encoding performance under a set of constraints

$$p_{opt} = \arg\max_{p} \sum_{i} \kappa_i \mathbf{V}(s_i, \mathbf{D}(\mathbf{E}(s_i, p)))$$

E **/** D**: video encoder / decoder**

V**: video quality metric**

si: video sequence

ki: weighting factor

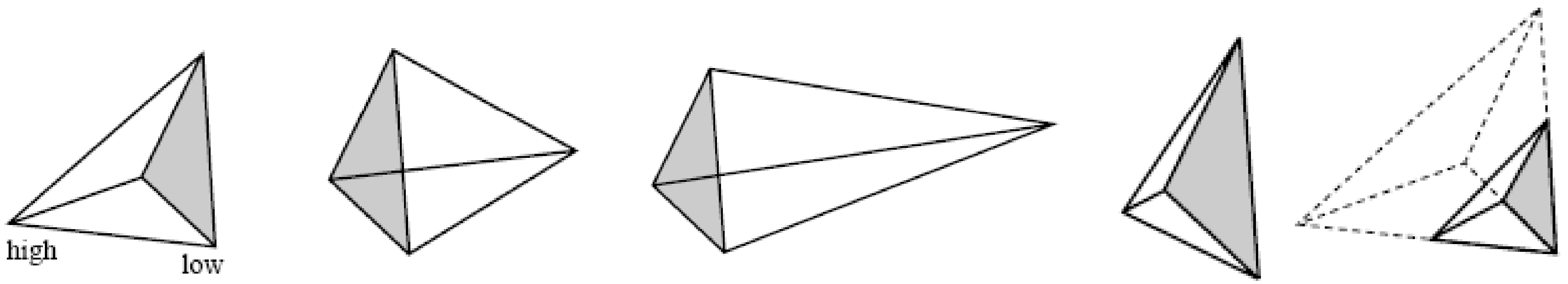
p: encoding parameters to be optimized

Constrained by a specific bitrate or, quality level

Video Quality Metric (VQM)

- Based on algorithms for objective measurement of video quality
- Correlates well with Mean Opinion Score (MOS) of subjective evaluation, as evaluated by VQEG
- Developed by NTIA / ITS, adopted as an ANSI and ITU standards
- Video Quality Metric has proven to be a very useful tool for not only for evaluation but also for parameter training
- VQM score: between 0 and 1
  - **0: no perceived impairment**
  - **1: maximum perceived impairment**
- Present results as “VQM-Rate” curves

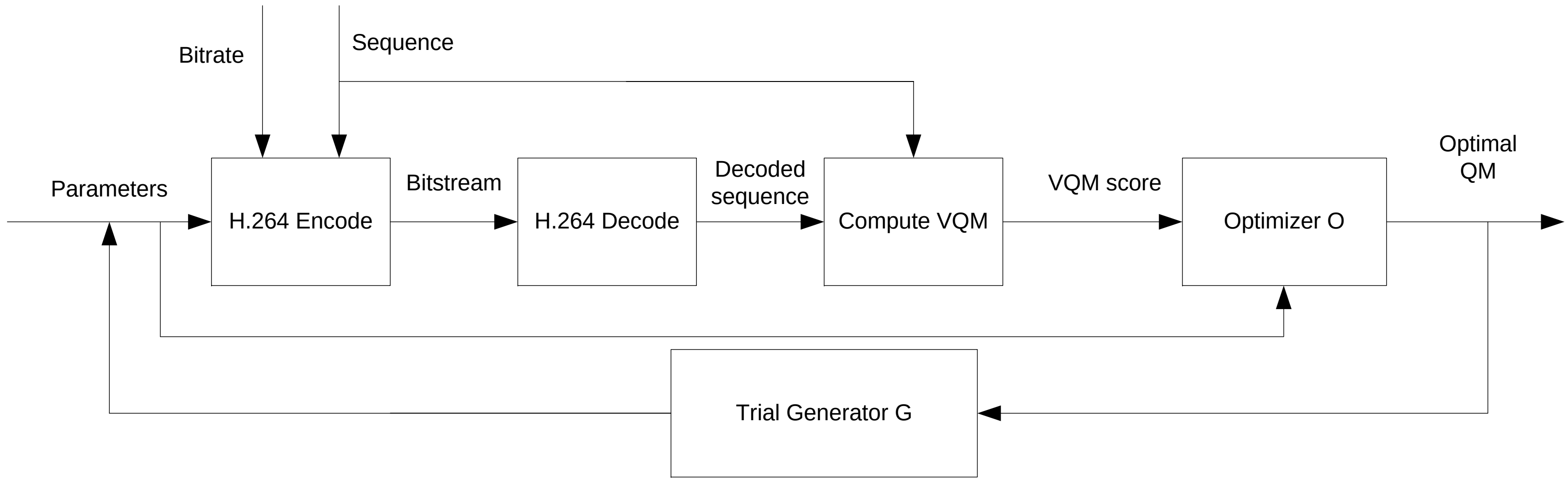
Downhill Simplex (Nelder-Mead) Search



simplex | reflection | reflection and Expansion | contraction | multiple contraction

- **Multidimensional search within an initial simplex, *n* dimensions correspond to *n* encoding parameters**
- **Downhill Simplex use:**
  - **simplex reflection**
  - **simplex expansion along minimization direction**
  - **simplex contraction along inverse minimization direction**
- **Efficient numerical search method only involving function evaluations**

Trial Based Training Framework



- **Parameter optimizer** O **control the iterations**
- **Parameter trial generator** G **generates one or more trial parameter via simplex transformation**

Example 1: MB Level Adaptive Quantization

MB Level Adaptive Quantization

- Set QP for each MB based on the local statistics
- MB level quantization step size is picture level quantization step size for an MB modulated by a factor
- The HVS is less sensitive to high motion areas, high frequency areas or areas where DC value is away from picture DC value, so a larger QP should be used in those areas

$$Q_{MB} = Q_{PIC} f_{mot} f_{hf} f_{dc}$$

MB Level Adaptive Quantization

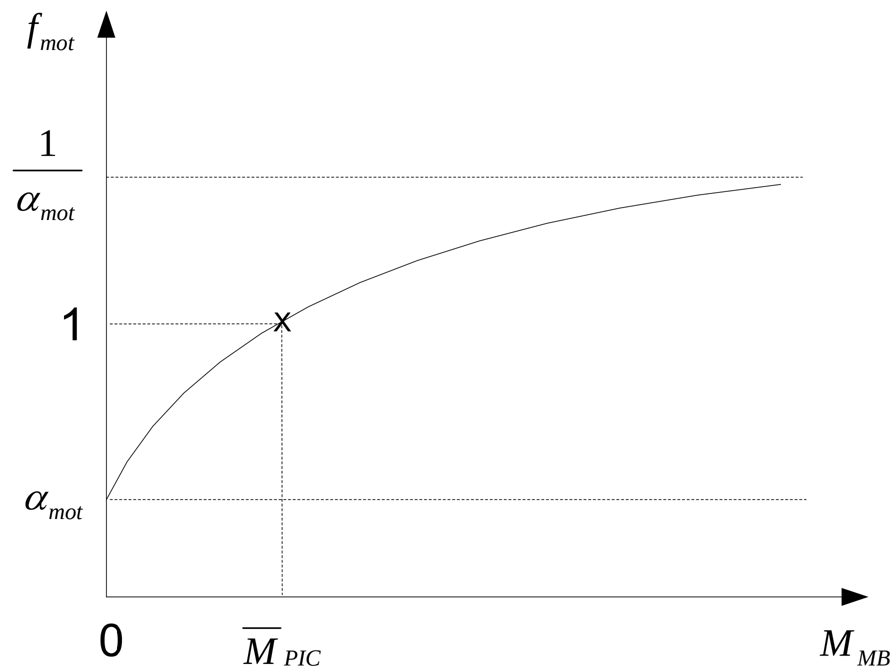
A linear fractional model for three modulation factors

$$\alpha_{mot}, \alpha_{hf}, \alpha_{dc}$$

$$f_{mot} = \frac{M_{MB} + \alpha_{mot}\overline{M}_{PIC}}{\alpha_{mot} M_{MB} + \overline{M}_{PIC}}$$

MB level QP is parameterized by three numbers

$$f_{mot}, f_{hf}, f_{dc}$$



Trial based training framework to obtain optimal configuration for the three parameters

MB Level Adaptive Quantization

A linear fractional model for all modulation factors

$$f_{mot} = \frac{M_{MB} + \alpha_{mot}\overline{M}_{PIC}}{\alpha_{mot} M_{MB} + \overline{M}_{PIC}}$$

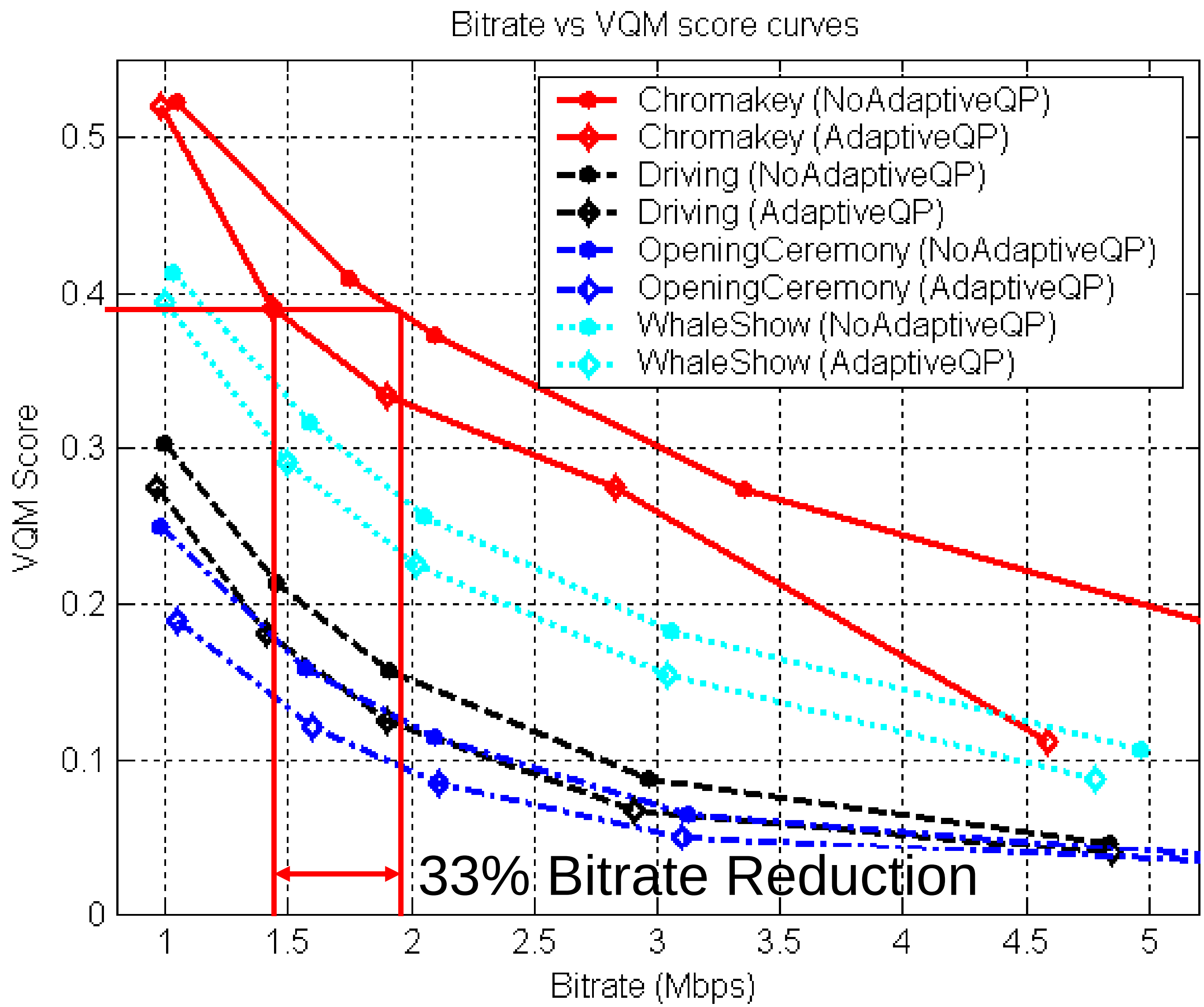
$$f_{hf} = \frac{H_{MB} + \alpha_{hf}\overline{H}_{PIC}}{\alpha_{hf} H_{MB} + \overline{H}_{PIC}}$$

$$f_{dc} = \frac{D_{MB} + \alpha_{dc}\overline{D}_{PIC}}{\alpha_{dc} D_{MB} + \overline{D}_{PIC}}$$

Logarithmic quantization step size to QP

$$qp_{MB} = qp_{PIC} + round(6\log_2(f_{mot} f_{hf} f_{dc}))$$

Simulation Results



Example 2: Quantization matrix (QM) in H.264 / AVC

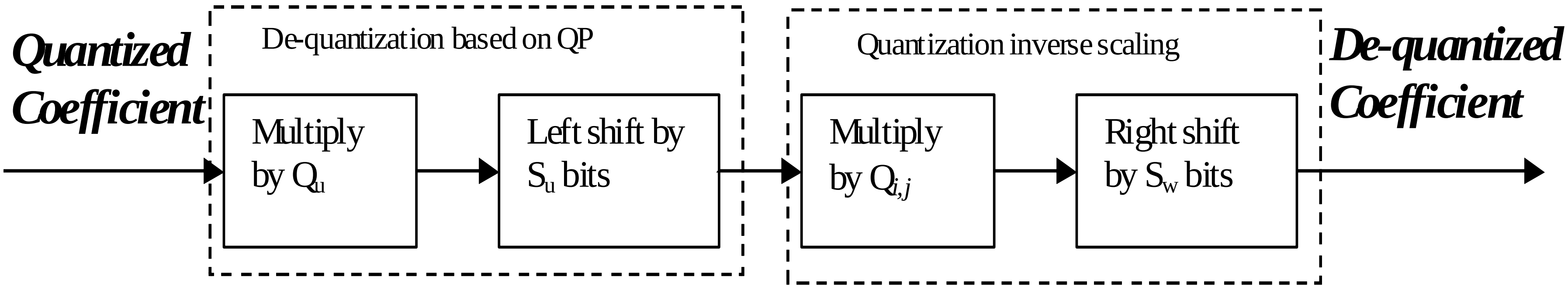
Quantization Scaling Matrix

- QM allows different weighting to be applied according to the sensibility of the Human Visual System (HVS) to a coefficient's corresponding frequency.

- PSNR is not a good metric to measure visual quality improvements for optimizing quantization matrices

- Quality metric which considers frequency response of HVS is important – VQM.

Quantization Scaling Matrix in AVC / H.264



Matrix $[Q_{ij}]$ is a Quantization scaling matrix

Defined to improve visual quality

Up to eight QMs in AVC/H.264

- Intra: 4x4Y, 4x4Cb, 4x4Cr, 8x8Y
- Inter: 4x4Y, 4x4Cb, 4x4Cr, 8x8Y

Specified in sequence and / or picture header

Standard defines 4 default matrices

QM Model is necessary to reduce search space

Default QM

Inter4x4

$$Q_4 = \begin{bmatrix} 10 & 14 & 20 & 24 \\ 14 & 20 & 24 & 27 \\ 20 & 24 & 27 & 30 \\ 24 & 27 & 30 & 34 \end{bmatrix}$$

Inter8x8

$$Q_8 = \begin{bmatrix} 9 & 13 & 15 & 17 & 19 & 21 & 22 & 24 \\ 13 & 13 & 17 & 19 & 21 & 22 & 24 & 25 \\ 15 & 17 & 19 & 21 & 22 & 24 & 25 & 27 \\ 17 & 19 & 21 & 22 & 24 & 25 & 27 & 28 \\ 19 & 21 & 22 & 24 & 25 & 27 & 28 & 30 \\ 21 & 22 & 24 & 25 & 27 & 28 & 30 & 32 \\ 22 & 24 & 25 & 27 & 28 & 30 & 32 & 33 \\ 24 & 25 & 27 & 28 & 30 & 32 & 33 & 35 \end{bmatrix}$$

QM Design

[Watson] **use the visibility of quantization error**

q**(x,y) = 2***T**(x,y)**

where T**(x,y) is the smallest coefficient that yields a visible signal**

[Wu et al] **maximize the ratio of distortion decrease to bitrate increase**

[Westen et al] **minimize a Lagrangian cost that involves bitrate and perceptually weighted distortion**

[Lee] **QM Modeling for 8x8 blocks:**

$$q(x,y) = a\left(\sqrt{x^2+y^2} - \frac{7}{\sqrt{2}}\right) + b\sin\left(\frac{\pi}{7\sqrt{2}}\sqrt{x^2+y^2}\right) + c$$

A Symmetric Quadratic QM Model

$$q(x,y) = a(x^2 + y^2) + bxy + c(x+y) + d$$

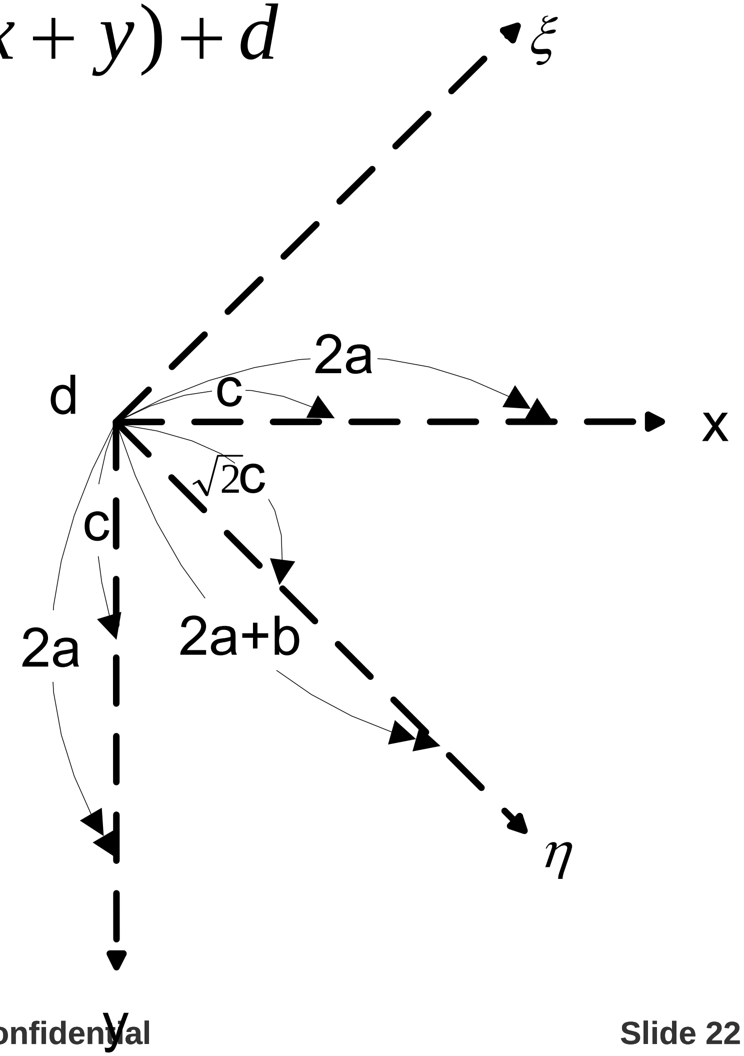
Symmetric $q(x,y) = q(y,x)$

Hankel* when $b = 2a$

Parameters

- ***a, b*** **characterize the convexity**
- **c characterizes the slope**
- ***d*** **represents DC stepsize**

Four parameters sufficient



***Hankel: constant positive sloping skew-diagonals matrix**

Modeling Default QM

Inter4x4

(a, b, c, d) = (-0.1875, -0.5500, 5.3125, 9.6750)

$$P_4 = \begin{bmatrix} 10 & 15 & 20 & 24 \\ 15 & 19 & 24 & 27 \\ 20 & 24 & 27 & 31 \\ 24 & 27 & 31 & 33 \end{bmatrix}$$

$$\| Q_4 - P_4 \|_E = 0.0256$$

Inter8x8

(a, b, c, d) = (-0.0290, -0.0563, 2.0712, 10.7535)

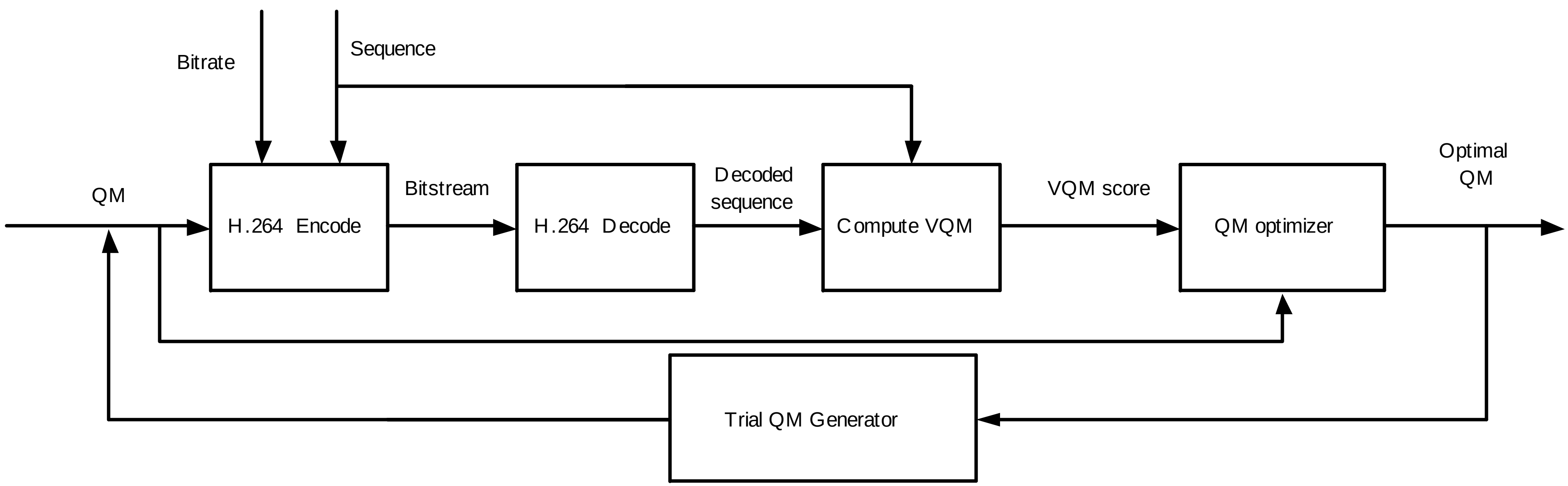
$$P_8 = \begin{bmatrix} 11 & 13 & 15 & 17 & 19 & 20 & 22 & 24 \\ 13 & 15 & 17 & 19 & 20 & 22 & 24 & 25 \\ 15 & 17 & 19 & 20 & 22 & 24 & 25 & 27 \\ 17 & 19 & 20 & 22 & 24 & 25 & 27 & 29 \\ 19 & 20 & 22 & 24 & 25 & 27 & 29 & 30 \\ 20 & 22 & 24 & 25 & 27 & 29 & 30 & 31 \\ 22 & 24 & 25 & 27 & 29 & 30 & 31 & 33 \\ 24 & 25 & 27 & 29 & 30 & 31 & 33 & 34 \end{bmatrix}$$

$$\| Q_8 - P_8 \|_E = 0.0248$$

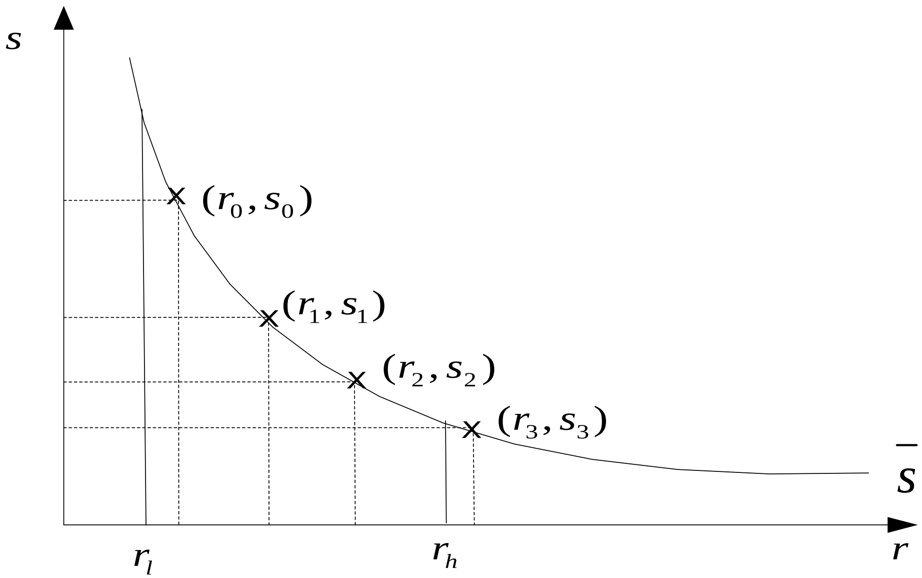
QM Design for Perceptual Coding

- QM design for a bitrate range via training
- Train QM for parameters (a, b, c, d) that maximize perceptual video quality measured by Video Quality Metric (VQM)
- Trial based multidimensional numerical search: Downhill Simplex Search

VQM Based QM Training



Average VQM (aVQM) Score Over a Bitrate Range



$$s = a_0 + a_1 r + a_2 r^2 + a_3 r^3$$

$$\begin{bmatrix} 1 & r_0 & r_0^2 & r_0^3 \\ 1 & r_1 & r_1^2 & r_1^3 \\ 1 & r_2 & r_2^2 & r_2^3 \\ 1 & r_3 & r_3^2 & r_3^3 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{bmatrix}$$

$$\bar{s} = \frac{1}{r_h - r_l} \int_{r_l}^{r_h} \left(a_0 + a_1 r + a_2 r^2 + a_3 r^3\right) dr$$

- **Model a VQM-rate curve based on four samples**
- **Third order model**
- **Average over a given bitrate interval**
- **Similar to AVSNR**

Simulation Results

Sequence (ARIB 480P)	aVQM Score		
	Default QM	Trained QM	Difference
Chromakey	0.4341	0.4197	0.0144
Driving	0.2465	0.2328	0.0137
Opening Ceremony	0.2193	0.2061	0.0132
Whale Show	0.4031	0.3891	0.0140
		Average	0.0138

Trained QM

Inter4x4

Inter8x8

,

$$T_4 = \begin{bmatrix} 11 & 18 & 29 & 44 \\ 18 & 27 & 40 & 56 \\ 29 & 40 & 54 & 71 \\ 44 & 56 & 71 & 90 \end{bmatrix}$$

$$T_8 = \begin{bmatrix} 11 & 14 & 18 & 23 & 29 & 36 & 44 & 53 \\ 14 & 18 & 22 & 28 & 34 & 41 & 49 & 59 \\ 18 & 22 & 27 & 33 & 40 & 47 & 56 & 65 \\ 23 & 28 & 33 & 39 & 46 & 54 & 63 & 73 \\ 29 & 34 & 40 & 46 & 54 & 62 & 71 & 82 \\ 36 & 41 & 47 & 54 & 62 & 71 & 80 & 91 \\ 44 & 49 & 56 & 63 & 71 & 80 & 90 & 101 \\ 53 & 59 & 65 & 73 & 82 & 91 & 101 & 113 \end{bmatrix}$$

*4x4 blocks and 8x8 blocks share the same QM model

Conclusions

- Introduced a systematic approach of configuring video encoding parameters for optimal video encoding using direct simplex search method
- Search method involves direct encoding of various sequences with different encoding parameter settings
- Applied successfully to find a set of optimal parameter values for MB level QP adaptation in H.264 / AVC, achieving 20-30% bitrate reduction
- Applied successfully to find optimal quantization scaling matrix, achieving 5-8 % bitrate reduction with similar perceptual video quality

Further Reading

- **This material is available from Proceedings of SPIE - Volume 6822, January 2008:**
  - **Huipin Zhang, Guy Cote, "Modeling quantization matrices for perceptual image / video encoding"**
  - **Huipin Zhang, Guy Cote, "Determining optimal configuration of video encoding parameters using numerical search algorithms"**
- **VQM references:**
  - **ANSI T1.801.03-2003, American National Standard for Telecommunications - Digital Transport of One-Way Video Signals - Parameters for Objective Performance Assessment**
  - **ITU-R Recommendation BT.1683, Objective perceptual video quality measurement techniques for standard definition digital broadcast television in the presence of a full reference, approved Jun. 2004.**
  - **9 ITU-T Recommendation J.144R, Objective perceptual video quality measurement techniques for digital cabletelevision in the presence of a full reference, approved Mar. 2004.**

Future Work

- Explore direct correlation of quantization matrix model parameters to the HVS
- Additional encoder parameters can be trained with the same method
- Ultimately develop low complexity encoder distortion metric that correlates better to MOS to integrate in an RD optimization encoder framework for internal parameter optimization

Questions?