Statistical Analysis and Distortion Modeling of MPEG-4 FGS

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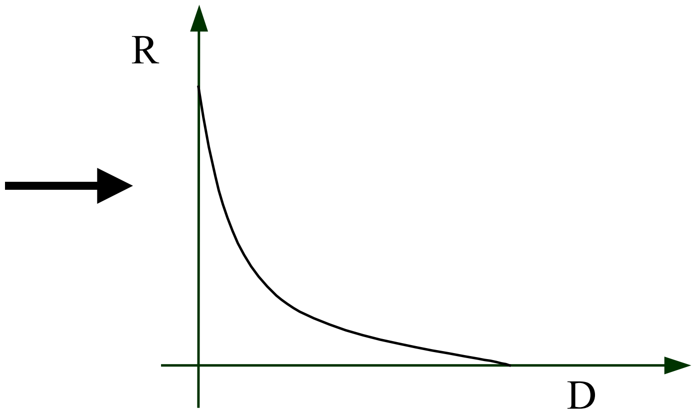
Background

- Rate-distortion (R-D) theory
  - The fundamental tradeoff in the design of any lossy compression system

A typical R-D curve



- R-D function:
  - A bound on achievable (or theoretically possible) distortion for a given coding rate
  - A powerful tool in Internet streaming

Background (cont.)

- Scalable coding is widely applied in Internet streaming
  - Provides the capability of recovering video information by partially decoding the compressed bitstream
  - Fine Granular Scalability (FGS) has been chosen in the MPEG-4 standard
- Fine granular scalability (FGS):
  - One low-bitrate base layer (BL) to provide a low, but guaranteed quality
  - One high-bitrate enhancement layer (EL) to provide fine quality improvement
  - EL can be truncated at any codeword

Motivation

- Current status:
  - No current closed-form R-D model can capture all the complexities of a real encoder
  - No specific work has been done on R-D modeling of scalable video coding for Internet streaming
- Goals in this paper:
  - Understand the statistical properties of FGS input and propose a more accurate statistical model for it
  - Study the bitplane coding process in FGS and derive a closed-form distortion model

Related work on Statistical Models

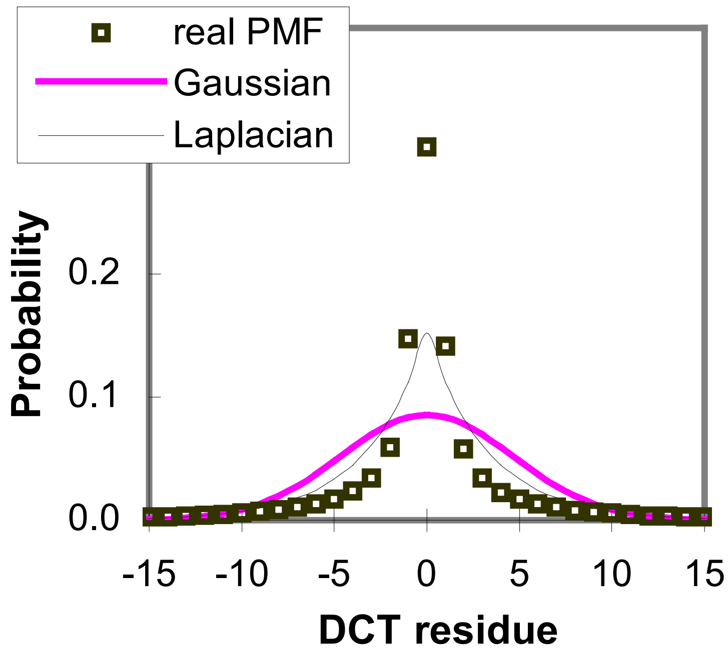
- Input to FGS EL:
  - DCT residue between the original image and the reconstructed image from BL
- The two most popular models of DCT residue:
  - Zero-mean Gaussian distribution:

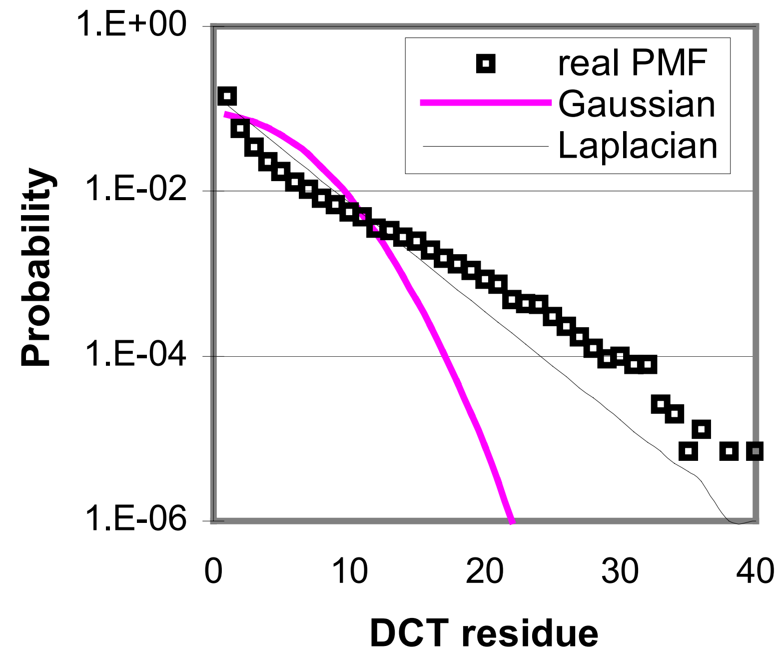
$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}}$$

  - Laplacian distribution (double exponential):

$$f(x) = \frac{\lambda}{2} e^{-\lambda|x|}$$

Related work on Statistical Models





- The PMF of DCT residue with Gaussian and Laplacian estimations in frame 0 of the Foreman CIF sequence (left). Logarithmic scale of PMFs for the positive residue (right).

Proposed Statistical Model

- Mixture Laplacian model:

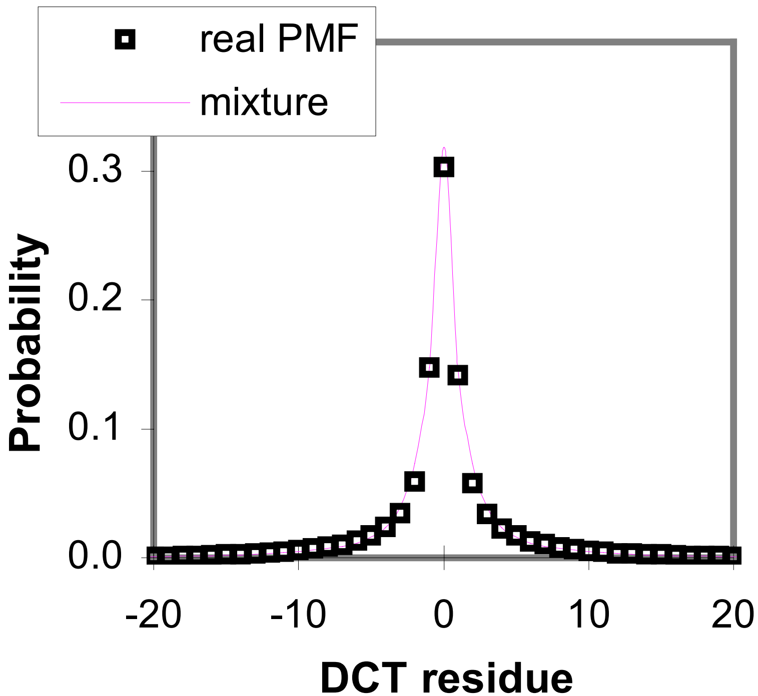
$$f(x) = p\frac{\lambda_0}{2}e^{-\lambda_0|x|} + (1-p)\frac{\lambda_1}{2}e^{-\lambda_1|x|}$$

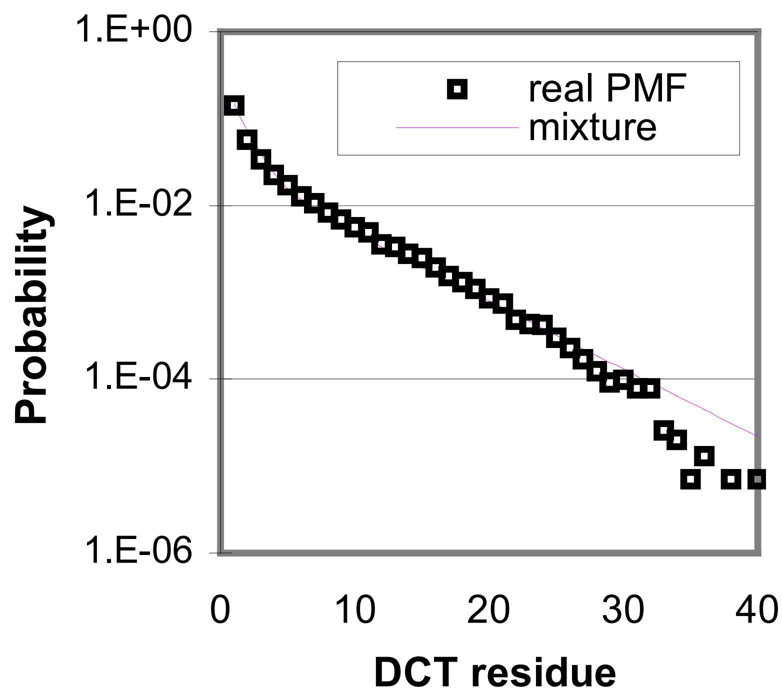
where λ_0 denotes the small variance Laplacian distribution and λ_1 denotes the large variance Laplacian distribution

- We use the Expectation-Maximization (EM) algorithm to obtain Maximum-likelihood (ML) estimation for parameters $\{ p, \lambda_0, \lambda_1 \}$

Results of Proposed Model

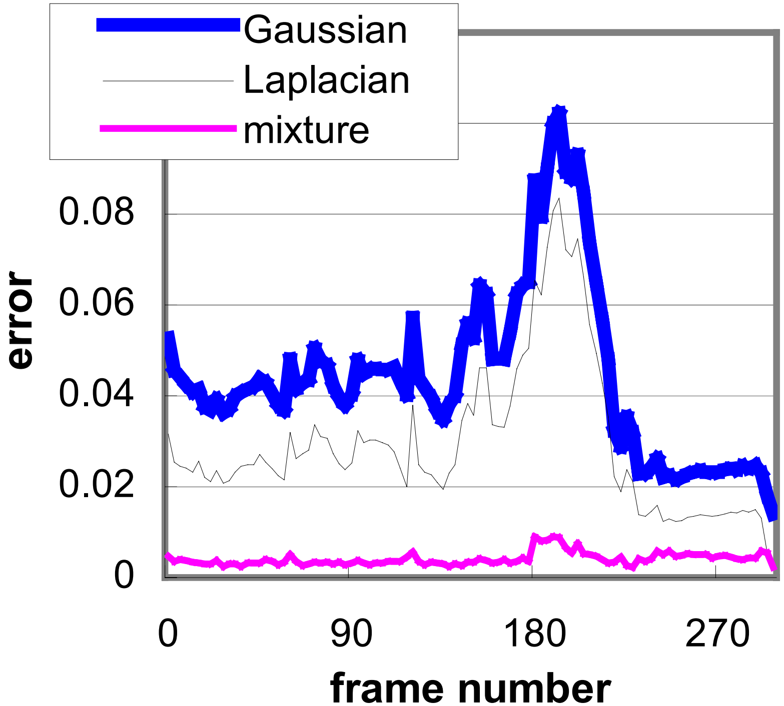
- The real PMF and mixture Laplacian (left) and the logarithmic scale of the positive part (right)

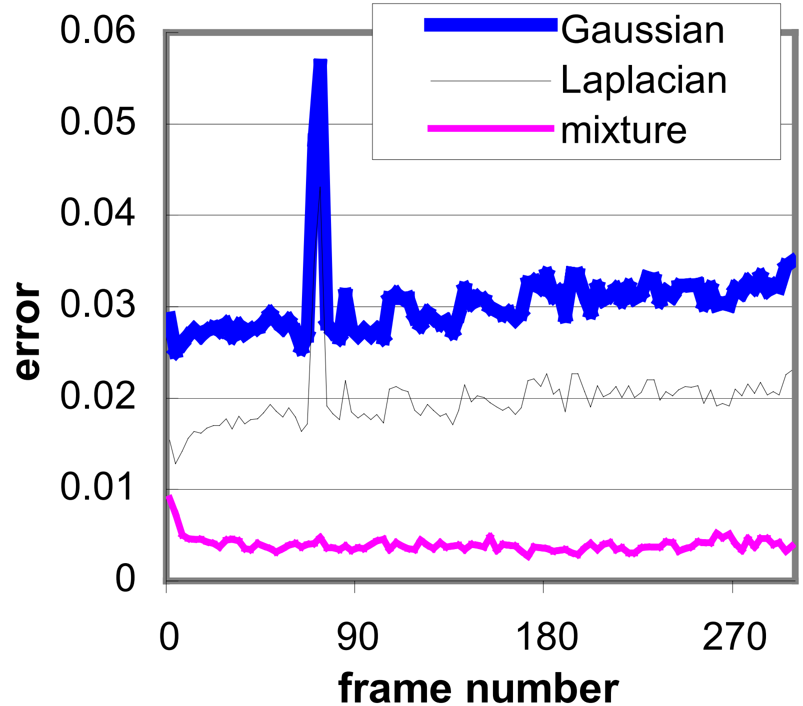




More Results

- The weighted absolute error of estimation in Foreman CIF (left) and Coastguard CIF (right)





All test sequences are coded at 10fps and 128 kb/s in the base layer

Current Distortion Models

- Classical model:

$$D = \varepsilon^2 \sigma_X^2 \, 2^{-2R}$$

where ε^2 is a signal-dependent constant, σ_X^2 denotes the signal variance and *R* is the bitrate

- A variation of the classical model (proposed by Chiang *et al*. in 1997):

$$R = aD^{-1} + bD^{-2}$$

where parameters *a*, *b* are obtained empirically

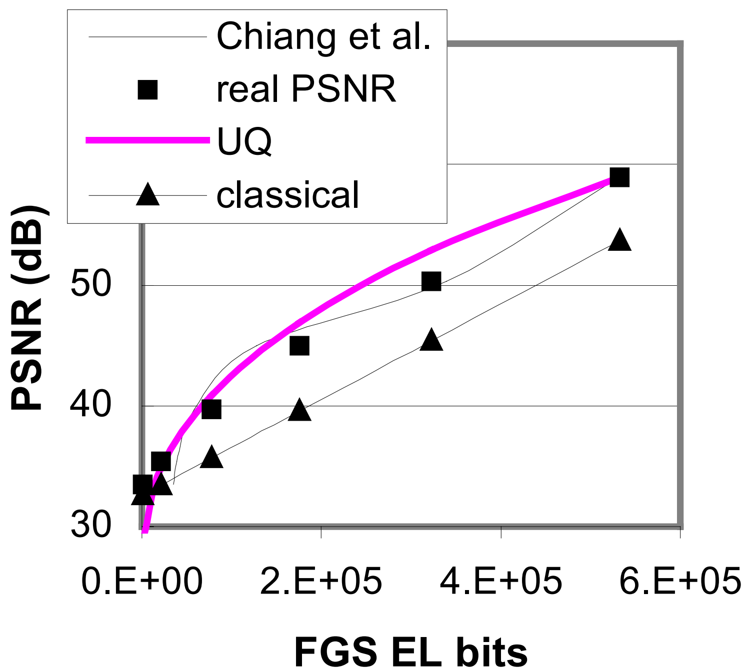
- Distortion model for Uniform Quantizer (UQ):

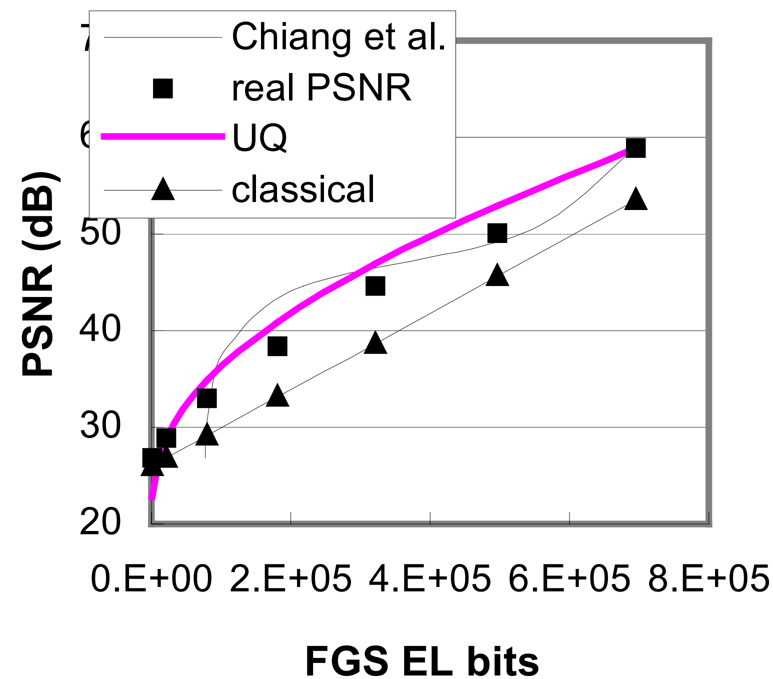
$$D(\Delta) = \Delta^2 / \beta$$

where Δ is quantization step and β equals 12

Performance of Current Models

- Performances of current models in frame 0 (left) and frame 252 of Foreman CIF (right)





A more Accurate Distortion Model

- For each component in the mixture-Laplacian model, the distortion is:

$$D_i(\Delta) = \frac{-1}{(1-e^{-\lambda_i \Delta})} \left\{ e^{-\lambda_i(\Delta-1)} \left[\left(\Delta - 1 + \frac{1}{\lambda_i} \right)^2 + \frac{1}{\lambda_i^2} \right] - \frac{2}{\lambda_i^2} \right\}, \; i = 0,1$$

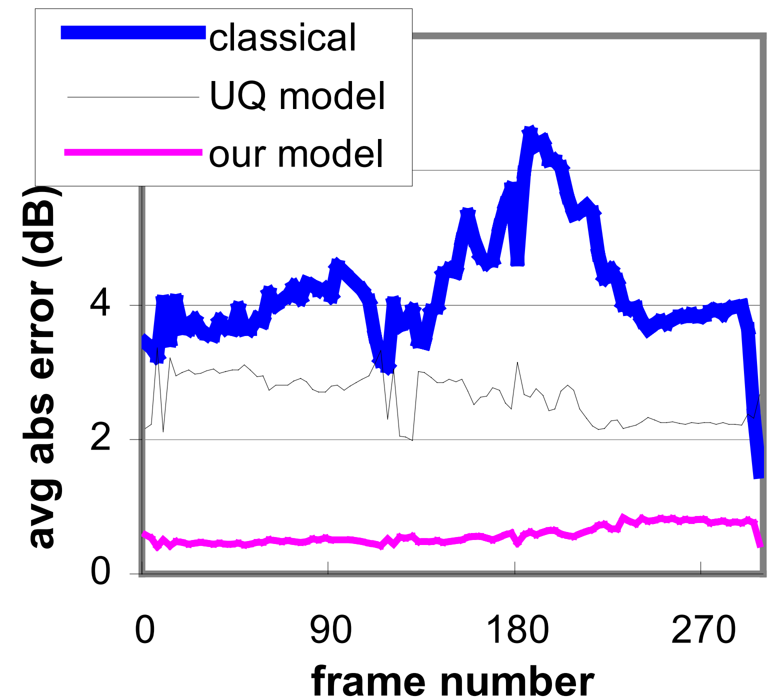
- Final version:

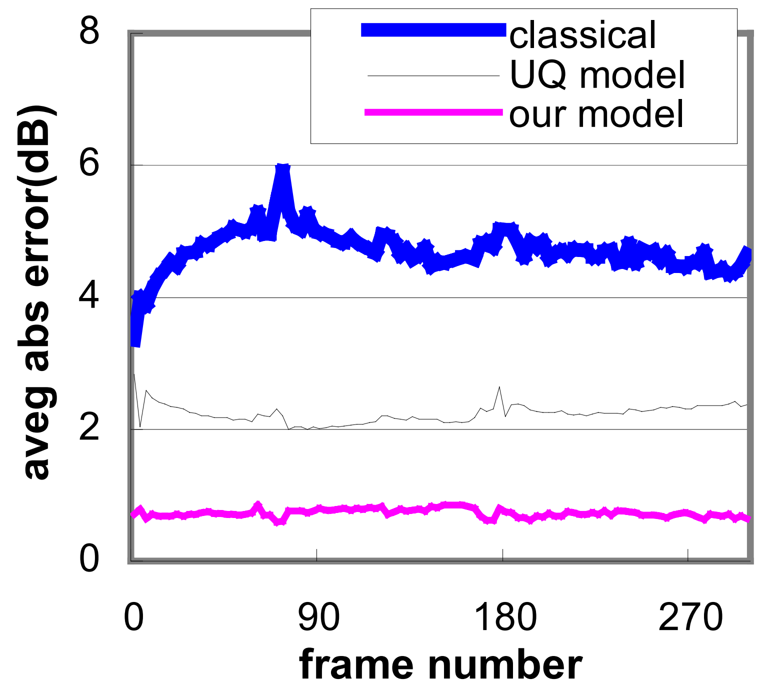
$$D(\Delta) = p \cdot D_0(\Delta) + (1-p) \cdot D_1(\Delta)$$

where Δ is the quantization step of each bitplane in the FGS EL and p is the probability of Laplacian component 0

Experimental Results

- The average absolute errors in Foreman CIF (left) and Coastguard CIF (right)





Conclusion

- This paper proposed an accurate statistical model for DCT residue
- Based on this statistical model, we derived a closed-form distortion function for FGS EL
- In summary, this paper provides a good starting point for further research on FGS streaming