Optimization techniques for adaptive quantization of image and video under delay constraints

Antonio Ortega

Submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
in the Graduate School of Arts and Sciences

Columbia University
1994

ABSTRACT

Optimization techniques for adaptive quantization of image and video under delay constraints

Antonio Ortega

Traditionally, rate-distortion (R-D) theory has been concerned with providing bounds on the optimal performance for various classes of coding algorithms and sources. In this thesis we depart from that approach in two ways. First, our objective are operational R-D results, i.e. we study algorithms that can find the optimal solution for a given coder configuration and known inputs, without relying on modeling either the encoder or the source. Second, we seek to explore explicitly other parameters that determine the achievable R-D performance, namely, the encoding delay and complexity, and the memory at the encoder.

We compute the optimal solution even if it requires too much complexity, memory or delay to be considered in a practical setting. Optimal schemes serve as a benchmark and can also be the basis for heuristic methods which provide slightly suboptimal but more efficient performance. More specifically we study the following topics:

(i) Optimal buffer constrained quantization. We find optimal solutions for the buffer control problem in a deterministic framework by assuming a long encoding delay. Our solution, based on dynamic programming, also leads us to short delay, lower complexity heuristics.

(ii) Rate control and policing constraints for video transmission over ATM networks. We study the problem of optimizing the source quality as in (i), while taking into account network considerations.

(iii) Optimization of dependent quantization environments. Optimal bit alloca-

tion results are presented for dependent quantization schemes (e.g. DPCM, predictive motion compensated video coding, MPEG).

(iv) Rate-delay trade-offs in a multiresolution image database system. We study how the bit allocation in a multiresolution coding system can be chosen so as to minimize the end-to-end query delay in browsing through a set of images.

(v) Adaptive quantization without side information. We propose a backward adaptive quantization algorithm where the input distribution is "learned" from past quantized samples. This allows adaptation to sources with unknown or time-varying input distribution.

List of Abbreviations

ATM – Asynchronous Transfer Mode

B – Bidirectionally interpolated mode (in MPEG)

CBR – Constant Bit Rate

DCT – Discrete Cosine Transform

DP – Dynamic Programming

DPCM – Differential Pulse Coded Modulation

GAP – Generalized Assignment Problem

HDTV – High Definition Television

HVS – Human Visual System

I – Intraframe mode (in MPEG)

JPEG – Joint Photographic Experts Group

KLT – Karhunen Loève Transform

LB – Leaky Bucket

MPEG – Moving Pictures Experts Group

MR – Multiresolution

MSE – Mean Squared Error

P – Prediction mode (in MPEG)

PSNR – Peak Signal to Noise Ratio

R-D – Rate–Distortion

SBC – Subband Coding

SMG – Statistical Multiplexing Gain

SNR – Signal to Noise Ratio

SR – Single resolution

TCM – Trellis Coded Modulation

TCQ – Trellis Coded Quantization

VBR – Variable Bit Rate

VA – Viterbi Algorithm

VLSI – Very Large Scale Integration

VQ – Vector Quantization

Acknowledgements

I would like to first acknowledge the continuous help and support from my thesis advisor and friend Professor Martin Vetterli. With his insights and suggestions Martin made this research both interesting and fun, never hesitating to share his many ideas and his endless supply of energy and enthusiasm.

I would also like to thank all my friends at the Image Lab and at CTR, especially Cormac Herley, Jonathan Hong, Thao Nguyen, and Kannan Ramchandran, for making it a pleasant work environment. In particular, I thank Alexandros Eleftheriadis, who has unselfishly contributed so much of his own time to keeping the Image Lab running.

I thank my family for their total support during my tenure at Columbia. I also thank my friends in New York for dragging me south of 110th St., or even across the river, every once in a while. I thank my friends in Madrid and elsewhere for their numerous stays at what was quickly nicknamed “Pensión Ortega”.

I had the pleasure to work with a number of people during my years at Columbia. I would like to thank Drs. Mark Garrett of Bellcore and Zhensheng Zhang of CTR for a very enjoyable collaboration. A special thanks goes to Kannan Ramchandran. I benefited greatly from the many hours spent working with Kannan on every stage of several projects, as well as from many discussions throughout my stay at Columbia. Our collaboration not only led to several joint publications but was also most enjoyable.

Some of the research presented here was initiated at the Universidad Politécnica de Madrid in Spain. I would like to thank Professors Narciso García and Guillermo Cisneros for advising my initial work at U.P.M. I also thank José Ignacio Ronda for a fruitful collaboration that was continued after my departure, demonstrating the usefulness of the Internet.

Professors Anastassiou, Chang, Kender and Silvotti I thank for serving on my defense committee.

Last, but certainly not least, I gratefully acknowledge the generous support of the Fulbright Commission and the Ministry of Education and Science of Spain, which made possible this research by granting me a scholarship for the duration of my stay at Columbia.

A mis padres